SCIENTIFIC AGRICULTURE

VOLUME 27 DECEMBER, 1947 No. 12

THE EFFECT OF CROP SEQUENCE UPON THE YIELDS AND QUALITY OF MARQUIS WHEAT

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[Received for publication July 23, 1947]

Experiments in crop sequence were begun in 1921 by the Field Husbandry Department of the University of Saskatchewan. One of the important objectives was to gain information about the effect of crop sequence upon the yield and quality of Marquis wheat. Factors used to determine quality included protein content in per cent, weight per bushel in pounds and weight per thousand kernels in grams. Records were also kept of the number of days required to mature the crop. In order to allow some time for the sequences to be established and to begin to influence the results, the data discussed in this paper begin with the year 1925.

The soil on the Investigation Field is classified as Elstow silty clay (11) and is popularly known as chocolate clay loam. The average precipitation for the period was 13.34 inches. The lack of moisture was the limiting factor in many of the seasons, tending to obscure the differences due to controllable factors. The rate of seeding used was five pecks per acre throughout the experiment. The time of seeding was early in the month of May, varying somewhat in different years, due to weather conditions, but all plots were sown at as close to the same date as possible each year, so that the different sequences were as nearly comparable as possible under field conditions.

LITERATURE REVIEW

Other investigators have been in close agreement that weeds, insect pests and plant diseases tend to increase when wheat is sown continuously, that yields are generally increased by sowing wheat on fallow, although the total wheat produced may not be increased when allowance is made for the land used for fallow. They have also agreed that the yield of wheat has been increased by growing it in rotations suitable for the region concerned and that factors influencing the availability of nitrogen in the soil, such as legumes and manures, have tended to increase the percentage of protein in the wheat to some extent. All seem to be agreed, however, that weather conditions favouring quick ripening have a more marked effect than soil treatment has upon the protein content.

In the following paragraphs, a few statements from various authorities will be cited in support of the above general statement. Hall (4) reported that at Rothamsted, England, the yields from wheat grown continuously were lower than from wheat grown in rotations and that the yield after

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fallow was also higher than from the continuous plots. Salter and Lill (13) reported from Ohio that wheat grown continuously yielded less than in any of the crop rotations. Etheridge and Helm (2) and Johnson (8) reported similar results from Missouri.

King, Arnason and Glen (9) reported from Saskatchewan that wire worm damage is often serious on fields that have been continuously in grain but they also pointed out that damage may be serious for at least a year or two after grass crops have been ploughed. Strickland (14) emphasized the increasing danger of wheat stem saw fly damage, when wheat is sown after wheat in Alberta.

Hopkins and Barnes (6), Hopkins (5) and Hopkins and Leahey (7) reporting for various Dominion Experimental Farms in the Prairie Provinces of Canada, indicated the value of frequent fallowing as preparation for wheat in order to control weeds and to conserve moisture for the ensuing crop. Although wheat on stubble sometimes gave good yields in favourable seasons, there were also frequent crop failures due to drouth or other factors.

Ellis (1) reporting from Manitoba found that there was very little variation in the protein content of wheat due to frequency of fallow or from clovers and grasses grown for a short time only. He pointed out that seasonal variations had a marked effect upon the protein content.

Metzger (10) reported from Kansas that wheat after alfalfa increased in protein content and that the longer the preceding field had been growing the alfalfa, the greater the protein percentage in the following wheat crop.

Throckmorton (15) also of Kansas, reported that the protein content of wheat was 15.3 per cent after alfalfa, 14.2 per cent after wheat and only 12.1 per cent after brome grass.

PLAN OF THE EXPERIMENT

Continuous crops of wheat were sown to compare with various rotations beginning with the simple two-field type, using fallow, corn and oats in cultivated double rows, as moisture conservation methods and continuing with longer rotations introducing perennial grasses and alfalfa and biennial sweet clover.

The financial returns obtainable from the hay or pasture crops are usually lower than those obtained from wheat and other grain crops, but in most cases the yields of grain have been increased sufficiently when grasses and legumes have been introduced, so that the average income per acre has compared favourably with straight grain growing sequences. This aspect of the subject has been discussed in a previous paper entitled Crop Rotation Experiments, Field Husbandry, Circular 507A. The present paper will confine itself to the effects observed upon the wheat crop only. The continuous cropping sequence was divided into two parts, R1 being manured at the rate of six tons per acre once in six years and R2 being left without any effort to conserve the soil's humus, except by means of the stubble and roots of the wheat.

Alternate cropping and moisture conservation methods were divided into three parts: O1, fallow wheat; O2, corn in hills 42 inches apart, and O3, oats in double rows 36 inches apart, followed by wheat in each case.

A three field rotation introducing sweet clover, sown with the wheat and using the same moisture saving methods as above, gave an opportunity to observe the effects produced by the sweet clover. This was recorded as Rotations T1, T2 and T3.

Rotation N, consisting of six fields was also divided into three parts in order to compare the effects of alfalfa, brome grass and slender wheat grass upon the yields and quality of wheat. This rotation consisted of fallow, wheat, oats in rows, wheat sown to alfalfa and to each of the grasses which were left three years after seeding, thus having two fields producing hay in each sequence. N1 included alfalfa, N2 brome grass and N3 slender wheat grass. All three of these rotations O, T and N were manured at the rate of six tons per acre, once in six years, preceding the fallow or row crop.

Rotation A represents a plan for introducing two methods of moisture conservation and one field of sweet clover in the same sequence. It occupies five fields as follows—fallow, wheat, corn, oats and sweet clover, the sweet clover being harvested for hay, the corn for fodder and the other crops for grain.

Rotation I is designed for the purpose of introducing a perennial, represented by alfalfa, into a crop sequence system. Fallow, wheat and oats occupy three fields with alfalfa on the fourth. The fallow, wheat and oats are rotated twice around while the alfalfa remains six years from time of seeding with the oats, thus producing alfalfa hay for five years. Every sixth year a new alfalfa field was sown with the oats and the old field was ploughed the following June for fallow.

Rotation S, fallow, wheat and oats represents a fairly common system of farming in Saskatchewan. No provision is made for conserving soil humus, except by means of the roots and stubble of the wheat and oats. It is similar to Rotation I except that there is no alfalfa.

DISCUSSION OF RESULTS

The average data for twenty years, 1925 to 1944, including yield of wheat in bushels per acre, protein content in per cent, weight per bushel in pounds, one thousand kernel weight in grams and days required to mature from time of seeding is given in Table 1.

During the economic depression, 1932 to 1939, inclusive, there were staff changes and reductions in grants so that the data regarding protein content, weight per bushel and thousand kernel weight were not taken consistently for Rotations A and I and are, therefore, omitted from Table 1, not being comparable to the twenty-year averages as recorded for the other crop sequences. The same is true for the weight per bushel data in Rotation S. During the first ten years when the data were recorded, there were no important differences in protein content, weight per bushel or per thousand, probably due to the fact that the different sequences had not been under way long enough to materially affect these factors in the wheat produced.

Effect of Manure

A study of the available data discloses that the use of manure at the rate of six tons per acre once in six years, equivalent to one ton per acre per year, R1, increased the average yield of wheat by 0.8 bushels per acre,

the protein content by 0.7 per cent, the weight per bushel by 0.4 pounds, the thousand kernel weight by 0.3 of a gram, and decreased by one the number of days required to mature as compared to R2, without manure.

Yields

The average yields of wheat in bushels per acre varied from 16.7 from continuous cropping (R1) to 33.3 obtained on fallow in Rotation I. The second highest average yield, 32.4 was obtained on fallow in Rotation O.

TABLE 1.—SUMMARY OF RESULTS WITH WHEAT IN THE DIFFERENT CROP SEQUENCES. AVERAGE YIELD IN BUSHELS PER ACRE, PROTEIN PER CENT, BUSHEL WEIGHT IN POUNDS, ONE THOUSAND KERNEL WEIGHT IN GRAMS, DAYS TO MATURE FOR TWENTY YEARS, 1925-1944

	Yield	Protein in per cent	Weight per bushel in pounds	Thousand kernel weight in grams	Days to mature
R^1 Continuous wheat manured	17.5	15.0	61.3	29.2	103
R^2 Continuous wheat, no manure applied	16.7	14.3	60.9	28.9	104
O^1 Fallow, wheat	32.4	15.1	61.2	30.1	106
O^2 Corn in hills, wheat	25.6	14.9	61.7	30.3	105
O^3 Oats in rows, wheat	21.7	14.3	61.5	30.1	104
T^1 Fallow, wheat, sweet clover	29.5	15.5	61.2	29.6	106
T^2 Corn in hills, wheat, sweet clover	26.6	15.5	61.4	30.4	106
T^3 Oats in rows, wheat, sweet clover	21.4	15.6	60.5	28.8	103
N^1 Fallow, *wheat*, oats in rows, wheat, alfalfa, alfalfa	26.4	16.4	60.7	28.3	104
N^2 Fallow, *wheat*, oats in rows, wheat, brome grass, brome grass	27.0	15.7	61.0	29.4	104
N^3 Fallow, *wheat*, oats in rows, wheat, slender wheat grass, slender wheat grass	29.8	15.8	61.3	29.5	104
N^1 Fallow, wheat, oats in rows, *wheat*, alfalfa, alfalfa	22.9	15.6	60.1	27.9	—
N^2 Fallow, wheat, oats in rows, *wheat*, brome brome grass, brome grass	23.6	15.0	60.1	29.3	—
N^3 Fallow, wheat, oats in rows *wheat*, slender wheat grass, slender wheat grass	22.9	15.1	60.3	29.6	—
A Fallow, wheat, corn, oats, sweet clover	31.5	—	—	—	106
I Fallow, wheat, oats, alfalfa	33.3	—	—	—	105
S Fallow, wheat, oats	28.7	15.4	—	30.8	105

In Rotation N, wheat on fallow after slender wheat grass produced 29.8 bushels per acre as compared to 27 on fallow after brome and 26.4 on fallow after alfalfa. In the wheat after oats in rows in this same rotation, four years after the different grasses and alfalfa, there was very little difference between the average yields obtained, indicating no difference in residual effect after that length of time.

In Rotations O and T, where fallow, corn in hills and oats in double rows were compared as methods of conserving moisture, the wheat yield on fallow ranked first, on corn ground second, and on land that produced oats in rows third, indicating that fallowing was the most efficient method of conserving moisture for the ensuring wheat crop. The values of the row crops, however, when added to the value of the wheat crop, exceeded the value of the wheat crop produced on fallow, indicating that row crops have a place in rotations on farms where they can be utilized to advantage. The wheat yields in Rotation T, where sweet clover is grown every third year, were lower than those in the two field Rotation O, except in the case

of wheat after corn, indicating that in the present state of soil fertility, frequent moisture conservation was more effective than introducing a legume, in influencing the yields of wheat. In Rotation S, wheat on fallow after oats, produced 4.6 bushels less than the wheat in Rotation I where alfalfa is used as a supplement, slightly less than wheat on fallow after sweet clover in Rotation T and 2.8 bushels less than wheat on fallow after sweet clover in the five field Rotation A. The yields of wheat, as well as general results on Rotations A and I, suggest the desirability of having a legume in the rotation and point the way to suitable systems for introducing them. Sequences A and I have proved to be definitely superior to T and N1 in this respect.

Protein Content

Introducing sweet clover in Rotation T increased the protein percentage of wheat by 0.4 on fallow, 0.6 on corn ground and 1.3 following oats in rows, as compared to that obtained in Rotation O. In Rotation N, wheat on fallow after alfalfa had an average protein content of 16.4 per cent as compared to 15.7 on fallow after brome grass and 15.8 per cent on fallow after slender wheat grass. The second crop of wheat in this rotation, following oats in rows, four years after alfalfa, gave 15.6 per cent of protein, as compared to 15 per cent after brome and 15.1 per cent after slender wheat grass. Rotation S, in which wheat follows fallow after oats, has given an average of 15.4 per cent of protein, which compares with 14.3 per cent produced by continuously grown wheat, without manure, R2 and with 15.1 per cent in Rotation O1, where wheat alternates with fallow.

A review of the annual data in detail indicates that weather conditions, particularly during the maturing period, influenced the protein percentage in the wheat. There was considerable evidence that warm dry weather during that period hastened maturity and increased the percentage of protein.

Weight per Bushel

The test weight per bushel of the grain has varied from 60.1 in Rotation N after oats in rows to 61.7 in Rotation O, after corn. In most cases, the weight per bushel has been lower in the wheat crop following a crop of oats in rows than in the crop following corn or fallow, but in all cases the average weight per bushel has been above the legal requirement of 60 pounds.

Weight per Thousand Kernels

The average weight per thousand kernels in grams has varied from 27.9 after oats in rows in Rotation N1 to 30.8 on fallow in Rotation S. As with the average test weight per bushel, the average weight per thousand kernels has tended to be a little lower after oats in rows than after corn or fallow. In Rotation N, the average weight per thousand was lower in the sequence containing alfalfa than in those containing grasses.

Days to Mature

The average time required for the wheat to mature has varied from 103 days for continuous cropping and after oats in rows in Rotation T3 to 106 days in several of the other rotations. In general, the wheat grown on fallow and corn ground has required two or three days longer to mature than when grown on land that produced oats in rows or wheat the preceding year.

SUMMARY

The results of this investigation emphasize, throughout, the fact that, in the existing state of soil fertility, moisture was the most important limiting factor in effecting the yields and quality of wheat. The findings are in agreement with those of other investigators as cited in the review of literature.

The yields were influenced also by manuring and by the introduction of alfalfa, sweet clover and grasses in the rotations. The method of introducing the legume was very important. Better yields were obtained in Rotation I where alfalfa remained six years, than in Rotation N where alfalfa remained only three years from the time of seeding. Likewise, yields were better in Rotation A, where sweet clover occurs once in a five field rotation, with two fields, fallow and corn for moisture conservation, than in Rotation T where sweet clover occurs once in three fields and moisture conservation is provided only once in three years.

Average protein content was increased by manuring as compared to no manuring and by the introduction of a legume, either sweet clover or alfalfa, in the sequence as compared to rotations without legumes.

Weights per bushel and per thousand kernels were influenced by the moisture factor, usually being higher after fallow or corn than after oats in rows.

In the existing state of soil fertility, where this study was made, the differences in wheat yields and quality due to crop sequence or manuring have not been so great as might be expected on older soils or soils of less natural fertility; but such gains as have been obtained are sufficient to point to the desirability of beginning now to take such measures as may be possible to conserve humus and nitrogen in prairie agriculture.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to Roy Hansen who collaborated in planning three of the rotations; to Trueman Stevenson and Howard Gerrie who supervised the field work; to Charles Anweiler who cared for the field plots, and to various other members of the Field Husbandry Department, past and present, who assisted in carrying on the many details involved in these experiments. They also wish to thank Dr. R. K. Larmour and other members of the Chemistry Department for their co-operation in making the protein determinations.

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DIGESTIBILITY STUDIES WITH RUMINANTS

XI. THE EFFECT OF THE NUTRITIVE RATIO OF A RATION UPON ITS DIGESTIBILITY BY CATTLE[1]

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[Received for publication August 1, 1947]

This series of studies on digestibility with ruminants was commenced in 1930. Although many digestibility trials had been carried out up to that time, no large scale systematic determinations had been made of the effect of various factors on the coefficients of digestibility of feedstuffs. It was, therefore, planned to investigate four factors, namely, (a) Associative Effects; (b) Plane of Nutrition; (c) Species of Animal; (d) Age of Animal.

Previous publications in this series have dealt with the two first factors, Associative Effects and Plane of Nutrition. The present publication reports the results on a particular phase of association. It deals with the possible effects of the nutritive ratio of a mixed ration on its digestibility.

There are two methods by means of which the nutritive ratio may be varied. Pure substances, such as casein or starch, may be added to a ration to vary the amounts of protein or carbohydrates, or the proportions of concentrates and roughages may be varied. With pure substances it is possible to obtain wider nutritive ratios but the rations would be unnatural as far as common practice is concerned. It was therefore decided to choose feeds commonly used in practice. These were: timothy hay as the roughage; soybean oil meal as the protein concentrate, and barley as the carbohydrate concentrate.

A description of the feeds is given in Table 1.

It will be seen that soybean oil meal was a commercial feed purchased on the market. The barley was grown at the Experimental Farm, and the timothy hay was of good quality consisting of approximately three-quarters pure timothy. These three feeds were fed singly to obtain base values

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TABLE 1.—DESCRIPTION OF FEEDS

Feed	Description	
Soybean oil meal	Can. Reg. No. 960.	Master Soybean Oil Meal, Toronto Elevators Limited
Barley	C. E. F. "Velvet", 1945 crop	
Timothy hay	Good quality, containing,	
	Timothy	73%
	Legumes	16%
	Couch grass	8%
	Sweepings and other weeds	3%
		100%

TABLE 2.—RATIONS FED

Ration No.	Feeds	Kg. per animal per day	Estimated nutritive ratio[6]
11	Soybean oil meal	3.0	1 : 1.2
12	Timothy hay Barley Soybean oil meal	5.0 2.0 1.0	1 : 6.8
13	Timothy hay Soybean oil meal	5.0 3.0	1 : 2.8
14	Barley	3.0	1 : 7.5
15	Timothy hay Barley Soybean oil meal	5.0 2.5 0.5	1 : 7.4
16	Timothy hay Barley Soybean oil meal	5.0 1.0 2.0	1 : 3.8
17	Timothy hay Barley	5.0 3.0	1 : 10.1
18	Timothy hay	7.0	1 : 15.2

[6] Based on Morrison's tables.

TABLE 3.—ARRANGEMENT OF RATIONS IN AN 8 × 8 RANDOMIZED LATIN SQUARE

Period No.	Ration numbers arranged by animals							
	An. 11	An. 12	An. 13	An. 14	An. 15	An. 16	An. 17	An. 18
1	11	17	16	13	12	14	18	15
2	14	12	11	18	16	13	15	17
3	17	11	18	14	15	16	13	12
4	12	13	14	16	17	15	11	18
5	15	16	17	11	18	12	14	13
6	13	14	15	12	11	18	17	16
7	18	15	12	17	13	11	16	14
8	16	18	13	15	14	17	12	11

and then in different proportions to obtain mixed rations with varying nutritive ratios. As a guide to the total quantities fed, Brody's (1) standards for maintenance were used.

In Table 2 are given the rations, the levels of feeding and the estimated nutritive ratios based on Morrison's tables. It will be seen that in the mixed rations the estimated nutritive ratios varied from 1 : 2.8 to 1 : 10.1.

Supplements of iodized salt, feeding oil containing vitamins A and D, wheat germ oil containing vitamin E, and a mineral mixture, including calcium, phosphorus, copper, iron, cobalt and manganese were given to the animals.

In this experiment, as in some previous experiments (4, 5) on associative effects with grains, base values for the grains were determined by feeding them alone. This might be criticized since the opinion has often

TABLE 4.—MEAN COEFFICIENTS OF DIGESTIBILITY OF DRY MATTER AND NITROGEN ARRANGED (1) BY PERIODS (2) BY ANIMALS. (MEANS OF EIGHT VALUES)[7]

Designation of mean	Coefficients of dry matter in per cent	Coefficient of nitrogen in per cent
Period 1	67.5	68.5
" 2	66.6	71.1
" 3	66.5	69.0
" 4	68.2	70.0
" 5	66.5	70.0
" 6	66.7	69.2
" 7	66.4	69.0
" 8	67.7	72.9
Range	1.8	4.4
F values[8]	1.06	2.29
Animal 11A	65.5	69.1
" 12	64.9	68.3
" 13	67.3	70.6
" 14	66.4	68.3
" 15	67.6	71.4
" 16	68.1	72.4
" 17	68.3	69.6
" 18	67.5	69.9
Range	3.4	4.1
F. value[8]	4.35	2.50

[7] Estimated missing values included in Means.
[8] Necessary F values for period at P of 0.05 = 2.23, at P of 0.01 = 3.08.
Necessary F values for animal at P of 0.05 = 2.24, at P of 0.01 = 3.10.

been expressed that cattle must have roughage in the ration for proper rumination and digestion. Our own experience has been that if digestion trials are not of too long a duration, grains and concentrates fed alone will be digested to an extent similar to their digestion when fed with hay. It was found (*loc. cit.*), for instance, that the digestibility of either barley or oil cake, when fed with hay did not differ appreciably from that when each was fed alone. With oats, the values obtained by calculation from a mixed ration with hay were somewhat lower than when oats were fed alone. In this connection Mead and Goss (3) carried out digestion trials with Holstein heifers that had been fed for eighteen months on rations without roughage. The values obtained were compared with another group which had received the same ration plus paper pulp. The results indicated that the digestibility of the ration was not affected by the lack of roughage.

In the present experiment soybean oil meal and barley were fed alone. They were also fed with hay. It was thus possible to compare the values obtained when they were fed alone with the values calculated when fed with a roughage.

Eight grade Shorthorns were used in the experiment. They were $1\frac{1}{2}$ years old and their average weight was 401 kilograms. Eight rations, listed in Table 2, were fed to the eight animals in an 8×8 randomized Latin square through eight periods as shown in Table 3.

The periods were 28 days in length. Four of these were a pre-experimental sub-period during which the animals received exercise and a standard

ration. Twelve days constituted the preliminary sub-period, followed by a collection sub-period of 12 days. The experiment was commenced in October, 1945, and completed in May, 1946.

In the progress of the experiment two values were lost due to feed refusals and one animal died. (Death was due to pneumonia caused by a broken window in the barn.) The dead animal, *No. 11*, was replaced by a spare one. In the statistical analyses of the data, account was taken of these facts.

To determine what influence the individuality of the animals or the period of the year might have on digestibility, the data for dry matter and nitrogen were arranged by periods and by animals. The mean values are given in Table 4. In view of the fact that there was more than one missing value, the data could not be statistically examined in the form of a Latin square. Instead, the method of Yates (6) was used to estimate the missing values when the data were arranged by rations and periods and also when they were arranged by rations and animals. When arranged by rations and periods, the values for animal *No. 11*, which died in the second period, and for animal *No. 11A*, which replaced it, were included. When arranged by rations and animals the values for animal *No. 11* were omitted. There were, therefore, three missing values in the first case and five in the second. The means shown in Table 4 include estimations of the missing values. The statistical analyses took these missing values into consideration. It will be seen that the agreement between periods and between animals was close. In the case of the animals, however, there was a statistically significant difference at the 1% point, animal *No. 12* being somewhat lower than the rest.

In Table 5 is given a summary of (a) the consumption of digestible nutrients in per cent of Brody's maintenance standards; (b) the mean nutritive ratios, and (c) the daily nitrogen balances. Too much significance

TABLE 5.—MEAN DAILY T.D.N. CONSUMPTION IN TERMS OF MAINTENANCE REQUIREMENTS (BRODY'S STANDARDS), MEAN NUTRITIVE RATIOS OF RATIONS AND MEAN DAILY NITROGEN BALANCES

Ration	T.D.N. consumption in per cent of maintenance	Nutritive ratio	Daily nitrogen balance (grams)
Hay	96	1 : 12.84	− 6.70
Barley	69	1 : 6.24	− 4.39
Soybean oil meal	91	1 : 1.04	+24.96
Hay + meal	144	1 : 2.63	+32.28
Hay; barley; meal : : 5 : 1 : 2	143	1 : 3.49	+20.92
Hay; barley; meal : : 5 : 2 : 1	130	1 : 5.07	+19.79
Hay; barley; meal : : 5 : 2.5: 0.5	135	1 : 6.37	+16.98
Hay + barley	138	1 : 8.41	+ 9.07

TABLE 6.—COMPARISON OF MEAN CALCULATED AND MEAN OBSERVED COEFFICIENTS OF DIGESTIBILITY OF MIXED RATIONS

Nutrient	Ration	No. of individual values	Mean coefficients of digestibility in per cent			"t" values*
			Observed	Calculated	Difference	
Dry matter	Hay + soybean meal	8	64.9	64.6	+0.24	0.373
	Hay: barley: meal : : 5 : 1 : 2	8	64.2	64.1	+0.09	0.117
	Hay: barley: meal : : 5 : 2 : 1	8	63.6	63.6	+0.09	0.174
	Hay: barley: meal : : 5 : 2.5 : 0.5	8	63.2	63.3	−0.06	0.075
	Hay + barley	7	62.6	63.0	−0.44	1.126
Organic matter	Hay + soybean meal	8	66.4	65.9	+0.48	0.740
	Hay: barley: meal : : 5 : 1 : 2	8	65.7	65.6	+0.11	0.139
	Hay: barley: meal : : 5 : 2 : 1	8	65.4	65.2	+0.20	0.394
	Hay: barley: meal : : 5 : 2.5 : 0.5	8	64.9	65.0	+0.10	0.127
	Hay + barley	7	64.3	64.8	−0.54	1.336
Nitrogen	Hay + soybean meal	8	77.5	78.1	−0.64	0.725
	Hay: barley: meal : : 5 : 1 : 2	8	75.1	75.0	+0.16	0.249
	Hay: barley: meal : : 5 : 2 : 1	8	70.6	70.0	+0.58	0.601
	Hay: barley: meal : : 5 : 2.5 : 0.5	8	67.0	66.3	+0.69	0.877
	Hay + barley	7	62.0	61.0	+1.01	1.259
Ether extract	Hay + soybean meal	8	59.9	57.9	+2.04	1.381
	Hay: barley: meal : : 5 : 1 : 2	8	55.2	51.8	+3.41	2.454
	Hay: barley: meal : : 5 : 2 : 1	8	47.6	43.8	+3.76	4.568
	Hay: barley: meal : : 5 : 2.5 : 0.5	8	45.7	39.0	+6.75	3.386
	Hay + barley	7	41.7	33.6	+8.07	3.001
Crude fibre	Hay + soybean meal	8	53.0	51.2	+1.86	1.811
	Hay: barley: meal : : 5 : 1 : 2	8	50.9	50.6	+0.35	0.170
	Hay: barley: meal : : 5 : 2 : 1	8	51.0	50.0	+1.06	1.011
	Hay: barley: meal : : 5 : 2.5 : 0.5	8	49.3	49.7	−0.39	0.217
	Hay + barley	7	42.4	43.2	−0.80	0.716
N-free extract	Hay + soybean meal	8	68.3	68.4	−0.09	0.146
	Hay: barley: meal : : 5 : 1 : 2	8	70.0	70.1	−0.11	0.158
	Hay: barley: meal : : 5 : 2 : 1	8	71.2	71.6	−0.35	0.664
	Hay: barley: meal : : 5 : 2.5 : 0.5	8	71.7	72.3	−0.52	0.916
	Hay + barley	7	72.0	72.9	−0.84	1.221
T.D.N. in dry matter	Hay + soybean meal	8	64.4	64.0	+0.46	0.788
	Hay: barley: meal : : 5 : 1 : 2	8	63.7	63.5	+0.24	0.317
	Hay: barley: meal : : 5 : 2 : 1	8	63.3	63.0	+0.31	0.658
	Hay: barley: meal : : 5 : 2.5 : 0.5	8	62.8	62.8	+0.01	0.014
	Hay + barley	7	62.2	62.5	−0.31	0.760

* Necessary "t" value for the hay + barley ration was 2.447 and for the remaining rations 2.365 at the 5% point.

TABLE 7.—COMPARISON OF MEAN OBSERVED AND MEAN CALCULATED COEFFICIENTS OF DIGESTIBILITY OF MIXED RATIONS OF HAY, BARLEY AND SOYBEAN OIL MEAL USING VALUES OF BARLEY AND MEAL CALCULATED FROM RATIONS WITH HAY

Nutrient	Ration (ratios of hay: barley: soybean oil meal	Mean coefficients of digestibility in per cent*			T values**
		Obs.	Cal.	Diff.	
Dry matter	5 : 1 : 2	64.2	64.1	+0.09	0.117
	5 : 2 : 1	63.6	63.3	+0.30	0.577
	5 : 2.5 : 0.5	63.2	62.9	+0.26	0.328
Organic matter	5 : 1 : 2	65.7	65.7	−0.01	0.012
	5 : 2 : 1	65.4	65.0	+0.41	0.799
	5 : 2.5 : 0.5	64.9	64.6	+0.26	0.331
Nitrogen	5 : 1 : 2	75.1	74.6	+0.48	0.754
	5 : 2 : 1	70.6	70.2	+0.42	0.435
	5 : 2.5 : 0.5	67.0	66.8	+0.14	0.177
Ether extract	5 : 1 : 2	55.2	55.2	−0.01	0.007
	5 : 2 : 1	47.6	49.2	−1.60	2.081
	5 : 2.5 : 0.5	45.7	45.5	+0.24	0.126
Crude fibre	5 : 1 : 2	50.9	51.5	−0.56	0.271
	5 : 2 : 1	51.0	50.0	+1.08	1.018
	5 : 2.5 : 0.5	49.3	49.2	+0.18	1.077
N-free extract	5 : 1 : 2	70.0	69.8	+0.25	0.362
	5 : 2 : 1	71.2	71.0	+0.24	0.460
	5 : 2.5 : 0.5	71.7	71.6	+0.18	0.317
T.D.N. in dry matter	5 : 1 : 2	63.7	63.7	+0.04	0.053
	5 : 2 : 1	63.3	62.9	+0.39	0.812
	5 : 2.5 : 0.5	62.8	62.6	+0.24	0.332

* Means of eight individual values.
** Necessary "t" at P of 0.05 = 2.228.

cannot be given to the nitrogen balances since they did not take into account the different periods and animals and the varying levels of feeding. They do indicate, however, the extent to which rations had or had not satisfied the requirements of the animals. The nitrogen balances for the mixed rations progressively decreased as the soybean meal was reduced and the barley increased. It will be seen from this table that the level of feeding ranged from approximately 0.7 maintenance to approximately 1.4 maintenance. The actual nutritive ratios of the mixed rations varied from 1 : 2.63 to 1 : 8.41.

Using the mean values for the hay, soybean oil meal and barley, obtained when these were fed alone, coefficients of digestibility of the mixed rations were calculated. The calculations were made by applying the mean coefficients of each nutrient to the amount consumed for each ration. These calculated values were compared with the observed values obtained in the digestion trials by the method of Fisher's (2) paired values. The "t" values were determined for the various series of differences so obtained.

In Table 6 are given the mean observed coefficients of digestibility, the mean calculated values and the differences between them. The "t" values of these differences for each nutrient in each ration are also included. The magnitudes of these differences were small. With the exception of the ether extract for three of the rations, there were no statistically significant differences between the observed and the calculated values.

As mentioned in the introduction, complete reliance was not placed upon the assumption that the digestibility of barley when fed alone and soybean meal when fed alone was an absolute base value. Digestibilities of these were also calculated from mixed rations with hay. Using these calculated values and the values of hay when fed alone, the coefficients of digestibility of the three rations in which the three feeds were fed were calculated. These were compared with the observed values. The results are given in Table 7. Here again, there were no statistically significant differences between the observed and calculated values.

Finally, the values for the barley and soybean oil meal when fed alone were compared with the values when calculated from the mixed rations. In Table 8 is given the comparison of digestibility of barley when fed alone with the digestibility calculated from the ration with hay. It will be noted that the magnitudes of the differences are, in general, small and not statistically significant.

In the case of ether extract the value calculated from hay was higher than when the barley was fed alone. In the case of crude fibre the opposite was found. In general, the digestibility calculated with the hay was slightly lower than when the barley was fed alone. These results were in agreement with those obtained in a previous investigation (4). For instance, in that investigation the barley, when fed alone, had 82.1 per cent T.D.N. in the dry matter while when it was fed with hay, the amount was 79.9 per cent. In this experiment the respective values were 82.0 and 80.9.

In Table 9 are given the values for the digestibility of soybean oil meal determined when it was fed alone, when calculated from the mixture with hay and when calculated from the three mixed rations with hay and

TABLE 8.—COMPARISON OF MEAN COEFFICIENTS OF DIGESTIBILITY OF BARLEY FED ALONE WITH MEAN COEFFICIENTS OF BARLEY CALCULATED FROM THE MIXED RATIONS WITH HAY

Designation	Mean coefficients of digestibility in per cent of the following nutrients						
	Dry matter	Organic matter	Nitrogen	Ether extract	Crude fibre	N-free extract	T.D.N. in dry matter
Fed alone*	80.9	82.8	75.0	69.0	22.8	89.7	82.0
Calculated from hay†	79.7	81.3	77.0	89.7	13.2	88.0	80.9
Difference	+1.2	+1.5	−2.0	−20.7	+9.6	+1.7	+1.1
"t" values‡	0.807	1.149	0.637	2.243	0.773	1.055	0.805

* Means of 6 values.
† Means of 7 values.
‡ Necessary "t" at P of 0.05 = 2.201.

TABLE 9.—COMPARISON OF MEAN COEFFICIENTS OF DIGESTIBILITY OF SOYBEAN OIL MEAL FED ALONE WITH MEAN COEFFICIENTS CALCULATED FROM THE MIXED RATIONS

Nutrient	Designation	Mean coefficients of digestibility in per cent of soybean oil meal*					
		Fed alone	Calculated from following rations				
			Hay + meal	Mixtures of hay, barley and meal in the proportion			Range
				5 : 1 : 2	5 : 2 : 1	5 : 2.5 : 0.5	
Dry matter	Means	84.2	84.8	84.6	84.9	82.9	2.0
	Stand. errors	± 0.81	± 1.69	± 3.00	± 4.05	±12.22	
	Coeff. of var.	2.7	5.6	10.0	13.5	41.7	
Organic matter	Means	85.2	86.4	85.8	86.8	83.2	3.6
	Stand. errors	± 0.88	± 1.56	± 3.16	± 4.00	±12.39	
	Coeff. of var.	2.9	5.1	10.4	13.0	42.1	
Nitrogen	Means	87.1	86.3	87.4	88.6	89.9	2.8
	Stand. errors	± 1.23	± 1.13	± 2.41	± 1.01	± 3.34	
	Coeff. of var.	4.0	3.7	7.7	3.3	10.5	
Ether extract	Means	91.4	94.8	99.3	106.7	140.1	†
	Stand. errors	± 0.25	± 2.49	± 3.26	± 3.54	±13.61	
	Coeff. of var.	0.8	7.4	9.3	6.0	2.75	
Crude fibre	Means	40.6	59.8	85.6	73.6	13.5	†
	Stand. errors	†					
	Coeff. of var.	†					
N-free extract	Means	88.6	88.3	88.0	84.8	77.3	11.3
	Stand. errors	± 0.57	± 1.85	± 3.30	± 5.42	±11.95	
	Coeff. of var.	1.8	5.9	10.6	18.1	43.7	
T.D.N. in dry matter	Means	84.4	85.6	85.3	86.6	84.9	2.2
	Stand. errors	± 0.84	± 1.54	± 2.90	± 3.65	±11.26	
	Coeff. of var.	2.8	5.1	9.6	11.9	37.5	

* Mean of eight values.
† Omitted because variation too large.

barley, using the barley coefficients determined when it was fed alone. The magnitude of the coefficient of variation is directly related to the nature of the ration. It was particularly large for the ration containing the smallest amount of soybean oil meal. For that reason the data were not examined by the method of Fisher's (2) intra-class correlation. Each mean for each nutrient was compared with each other mean by Fisher's (*loc. cit.*) "t" method for small samples. In general, there were no statistically significant differences between the values for the meal obtained when it was fed alone and between those obtained by calculation from the various rations. Further, the magnitudes of the differences with the exception of the ether extract and crude fibre and, in one case, the nitrogen-free extract were small.

In view of the above data the following conclusion is justified. For rations containing a protein concentrate, a carbohydrate concentrate and a roughage, the nutritive ratio does not influence the digestibility between the approximate range of 1 : 2 to 1 : 9.

SUMMARY AND CONCLUSION

Using timothy hay, barley and soybean oil meal, mixed rations were made up with nutritive ratios varying from 1 : 2.63 to 1 : 8.41.

The coefficients of digestibility of these rations were determined with eight grade shorthorn steers.

The coefficients of digestibility of the individual feeds were also determined.

These latter coefficients were used to calculate the coefficients of digestibility of the mixed rations.

By comparing the coefficients so calculated with those obtained in the digestion trials it was shown that the nutritive ratio of the mixed rations did not influence their digestibility.

ACKNOWLEDGMENTS

Grateful acknowledgment is given to the Division of Botany, Science Service, for the botanical analysis of the hay.

The Division of Animal Husbandry undertook the responsibility of supplying the animals and maintaining their health.

Technical assistance in carrying out the experiment was rendered by Messrs. W. Angus and P. Lalonde.

The feeding stuffs analysis of the samples was carried out by the Plant Chemistry Unit in this Division, under the direction of Mr. R. B. Carson.

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APPENDIX

Table 10.—Chemical composition of feeds (means of eight values)

Feed	Dry matter	Composition of dry matter				
		Ash	Protein*	Ether extract	Crude fibre	N-free extract
	%	%	%	%	%	%
Timothy hay	88.54	5.60	8.16	1.78	34.78	49.68
Barley	85.59	3.11	13.95	1.84	6.56	74.55
Soybean oil meal	91.01	6.22	42.80	3.94	6.10	40.95

* Protein factors: Timothy, 6.25; barley, 5.83; Soybean oil meal, 5.71.

BARN CURING HAY[1]

W. Kalbfleisch[2], M. F. Clarke[3] and P. O. Ripley[4]

[Received for publication August 19, 1947]

The curing of grass and legume crops grown during the summer to provide winter feed for live stock has been a problem for many centuries. Two general methods of handling the crops have been investigated, namely, preserving in a comparatively fresh state as silage; or drying in order to prevent mould development and fermentation, and thus provide favourable conditions for storing the forage to maintain it in as palatable and nutritive condition as possible. In most cases the drying has been done in the field, using natural drying forces such as wind and sun, with attempts to assist nature and hasten drying by various mechanical means which man's ingenuity could devise. In this connection such devices as tedders, swath turners, side delivery rakes, mower-crushers and tripods are a few of the developments evolved in an attempt to shorten the period required to make high quality hay under field conditions. In many localities, however, periods of sunshine are so short and intermittent that some artificial assistance is necessary to produce feed of highest quality. Rapid dehydration of freshly cut material by means of forced draft and high temperatures produces a highly satisfactory product under all types of conditions, but the fixed costs and operating expenses are so high that the method is adaptable only to large scale commercial operations in the manufacture of specialized feeds. Under average farm conditions the quantities of feed grown are not sufficient to justify the expenditure of several thousand dollars in dehydrating equipment. For such requirements some modification of the artificial dehydration method which could be carried out at a comparatively low cost would seem desirable.

ARTIFICIAL CURING OF HAY

In recent years attempts have been made to shorten the period of field curing by drying or partially drying the forage in stacks or barns. The records indicate that drying hay artificially was first attempted in England about 1870 (1). In 1911, A. J. Mason built an experimental dryer at West Point, Mississippi. An enormous amount of experimental work and industrial development has taken place since that time. These methods in the main required rather high priced installations, and the cost per ton of drying was prohibitive except on an industrial scale.

The search in this artificial drying was always toward a low cost method. A method of forcing air through the mass of green forage was first attempted by Neilson of England (2) in 1894. Atmospheric air was forced through a hollow centre stack of green hay by means of a fan. In 1905 a barn drying unit was set up at Ohio State University (3). These early attempts were made in an effort to completely dry the hay with no field curing. They required the handling of the large amount of moisture in freshly cut forage. In 1934 the University of Tennessee (4) commenced investigations on partially drying forage in the field and completing the

[1] Results of experiments at the Central Experimental Farm, Ottawa, and the Dominion Experimental Farm, Agassiz, B.C.

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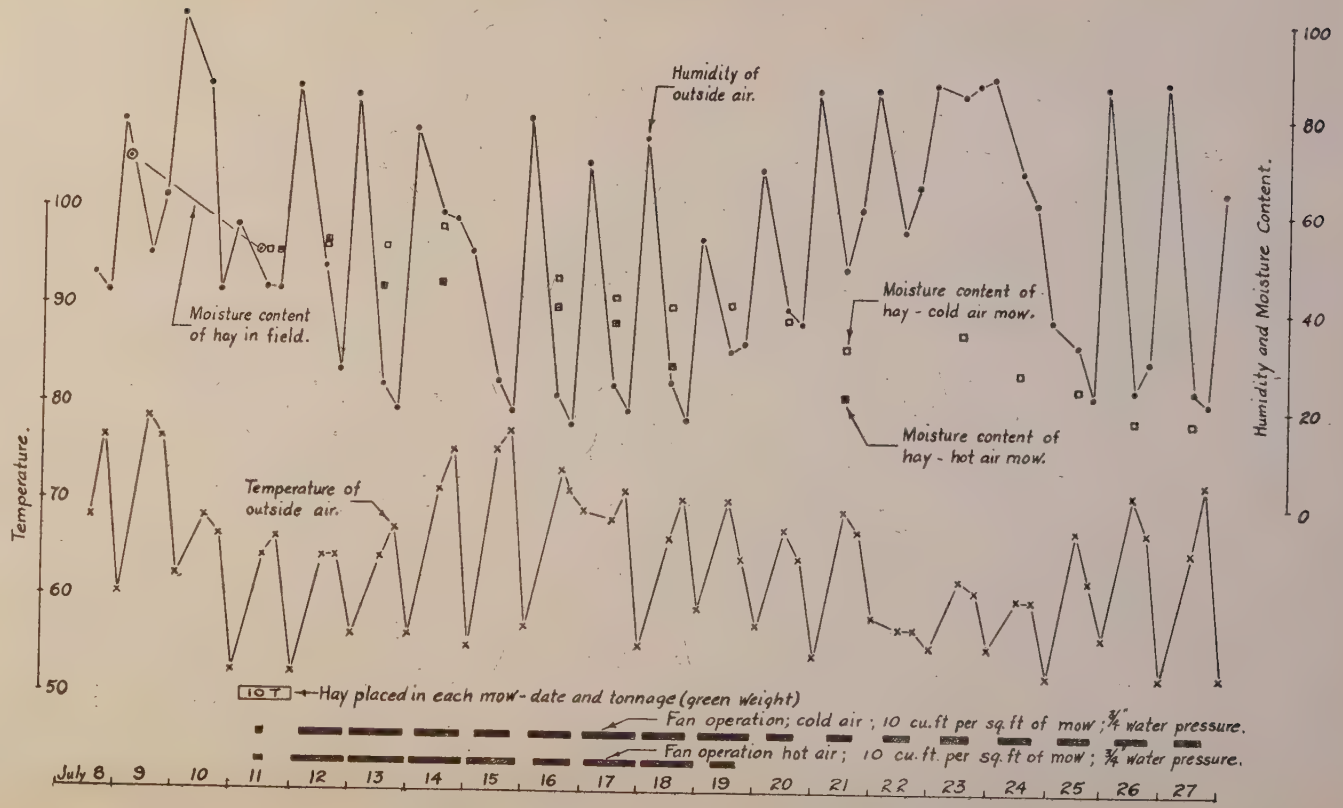
Figure 1

C.E.F. HAY DRIER

Test No 2 - 1st Cut - July 1945

Duct Distribution System - Mow Size 15' x 40' - Depth of Hay 6'

EXPERIMENTAL FARMS SERVICE OTTAWA


Humidity of outside air.
Moisture content of hay in field.
Moisture content of hay - cold air mow.
Moisture content of hay - hot air mow.
Temperature of outside air.
Temperature.
Humidity and Moisture Content.
100
90
80
70
60
50
100
80
60
40
20
0
10 T ← Hay placed in each mow - date and tonnage (green weight)
Fan operation; cold air ; 10 cu.ft per sq.ft of mow ; ¾" water pressure.
Fan operation hot air ; 10 cu.ft. per sq.ft of mow ; ¾ water pressure.
July 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27

process by blowing air through the hollow centre of long stacks or ricks in the field. This still left the hay exposed to the elements unless covered by tarpaulins which again added to the labour and the cost.

In 1939, Weaver and Wylie (5) reported a scheme for completing the process of drying in the barn by forcing air, by means of a fan, through ducts installed in the bottom of the mow. The air in turn was directed from outlets in the ducts through the mass of hay spread uniformly over the ducts. Thus began the method of partially barn drying hay. Some changes have been made in the details of the system by later investigators. In the main, however, the general plan is to force either artificially heated or natural atmospheric air through the hay mass in order to complete the drying process.

Some of the advantages claimed for the process are:

1. Shorter field drying period and thus less danger of spoilage from unfavourable weather.
2. By drawing from the field in a wilted or partially dried condition less loss of leaf occurs thus retaining a larger proportion of protein and other nutritive elements.
3. Shorter field curing results in a greater retention of carotene.
4. It is claimed that a better quality of hay, generally, is obtained by barn curing.

BARN CURING INVESTIGATIONS

Central Experimental Farm, Ottawa, 1944 Test No. 1 and 1a

In 1944, two hay curing installations by the Field Husbandry Division, at the Central Experimental Farm, Ottawa, were constructed in a mow which was divided into two sections and provisions were made to operate one unit with cold air and one unit with heated air. The fans and distribution system used in these units were identical and the details of the equipment are shown in Table 1. Heated air was supplied for the hot air drier in one section by a standard household furnace with a capacity of 150,000 B.T.U.'s when fitted with an automatic oil burner. The heat supplied by this furnace raised the temperature of the air from 18 to 28 degrees above the atmospheric temperature. In the other section cold air was supplied. On June 22, 6.4 tons of alfalfa hay were placed in each section of the mow at a moisture content of 43 per cent, and between June 22 and June 29 the cold air fan operated 58 hours and the warm air fan 96 hours. The fuel consumed by the burner was 16.7 gallons per ton of dry hay at a cost of $2.00 per ton. In the 1944 tests the cold air fan was only operated for an hour or two each night. Rain occurred on two days and two nights in the 8-day drying period and both systems were run only at short intervals during the rain. Although the quality of the dried hay was somewhat better in the hot air mow, the hay heated in numerous spots in both mows and there was no apparent improvement in quality over field-cured material.

From the operation of the hay curing equipment in 1944 it was found that almost continuous operation of the fans would be necessary to prevent heating; that the distribution of hay and the even distribution of air were two of the major problems in operating a curing unit, and that the use of a heating unit involved a possible fire hazard which made it necessary to keep a watchman with the equipment for both night and day operation. Moreover, the air supply at 8 cu. ft. per min. per sq. ft. of mow did not appear adequate with either system.

TABLE 1.—BARN HAY CURING EQUIPMENT DETAILS, CENTRAL EXPERIMENTAL FARM, OTTAWA, DOMINION EXPERIMENTAL FARM (STATION), AGASSIZ, B.C., STE. MARTINE AGRICULTURAL SCHOOL, STE. MARTINE, P.Q. (OBSERVATIONS ONLY)

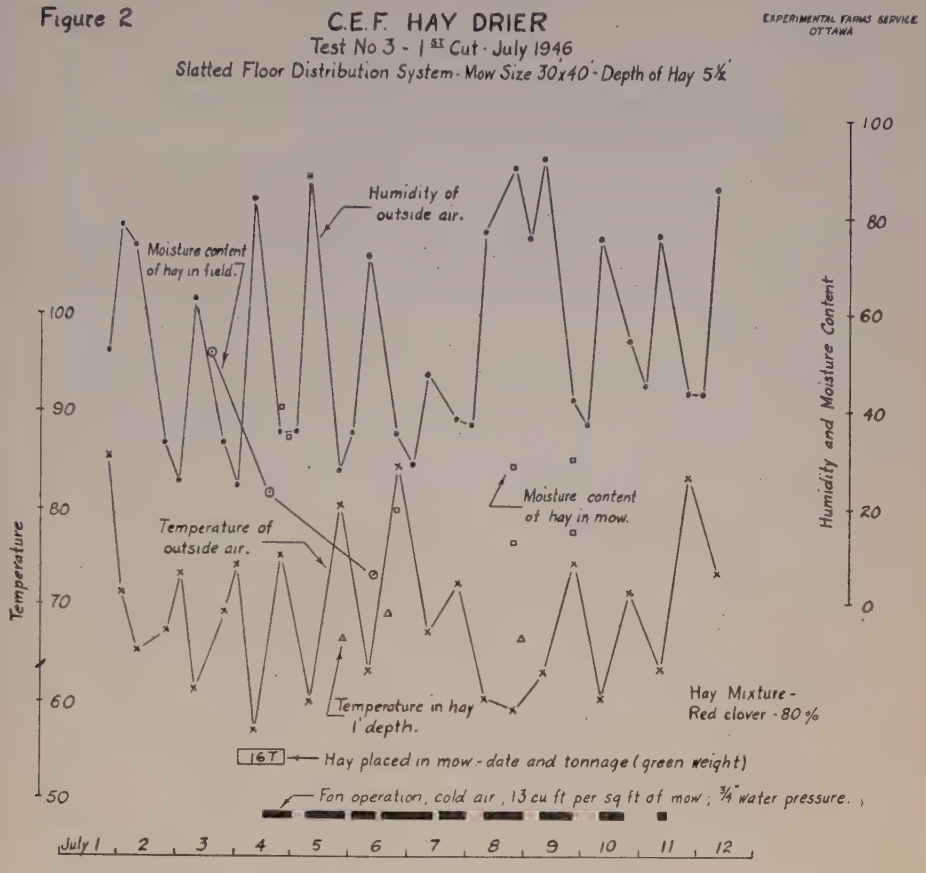
Test No.	Location of installation	Date	Mow size, ft.	Air supply	Air in cu. ft. per sq. ft. per min.	Air press. inches water	Distribution system	Main duct size	Lateral size	Power unit and h.p.	Initial moisture in hay, %	Hay tonnage, green, wt.	Drying days	Fan, hrs.
1	Ottawa	1944	16 × 40	Cold	8	½	Main duct with laterals spaced 5 feet apart	23″ × 23″ × 26′	6″ × 8″ × 9′*	Gas. Eng.	43	6.4	8	58
1a	Ottawa	1944	16 × 40	Hot	8	½	Same as item one	23″ × 23″ × 26′	6″ × 8″ × 9′	Gas. Eng.	43	6.4	8	96
2	Ottawa	1945	16 × 40	Cold	12	1½	Same as item one	23″ × 23″ × 26′	6″ × 8″ × 9′	Gas. Eng.	50	10.0	17	165
2a	Ottawa	1945	16 × 40	Hot	12	1½	Same as item one	23″ × 23″ × 26′	6″ × 8″ × 9′	Gas. Eng.	50	10.0	9	250
3	Ottawa	1946	30 × 40	Cold	13	0.35	Main duct and slatted floor with control dampers	24″ × 68″ × 25′	12′ × 15′	Gas. Eng.	40-30	16.4	8	112
4	Ottawa	1946	30 × 40	Cold	15	0.75	Same as item 3	Tapered as above	(Hay placed on item 5)		35	24.0	21	321
1	Agassiz	1946	30 × 36	Cold	14.8	¾	Main duct and lateral ducts	22″ × 78″ × 29′	12″ × 8″*	Motor 5 h.p.	42-36-51	22.5	11	151
2	Agassiz	1946	30 × 36	Cold	14.8	¾	Main duct and lateral ducts	22″ × 78″ × 29′	12″ × 8″	Motor 5 h.p.	47-39-29	18.3	13	159
3	Agassiz	1946	30 × 36	Cold	14.8	¾	Main duct and lateral ducts	22″ × 78″ × 29′	(Hay placed on top of test 2).		42-34-22	12.6	11	123
1	Ste. Martine	1946	30 × 36	Cold	11	¾	Main duct and slatted floor	(Observations on operation)		Motor 3 h.p.	About 50	—	15	360

* Main duct tapered. Laterals of inverted U-shaped box type.

TABLE 2.—CHEMICAL ANALYSES OF BARN CURED AND FIELD CURED HAY, DOMINION EXPERIMENTAL FARM, AGASSIZ, B.C., 1946

	Per cent composition on a dry matter basis							
	Ash	Calcium	Phosphorous	Protein (N × 6.25)	Ether extract	Crude fibre	Nitrogen free extract	Carotene Mg./100 gms.
	%	%	%	%	%	%	%	
Test No. 1								
Barn cured	5.80	1.30	0.19	10.98	1.15	35.36	46.50	3.58
Field cured	4.95	0.76	0.16	8.18	8.83	41.70	44.34	1.61
Test No. 2								
Barn cured	7.98	1.07	0.26	12.22	1.30	34.06	44.44	4.30
Field cured (swath)	5.64	1.08	0.18	10.07	1.23	31.58	51.48	3.51
Field cured (cocked)	5.15	1.01	0.23	13.34	1.39	32.25	47.87	3.82
Test No. 3								
Barn cured	6.61	1.26	0.24	14.37	1.49	32.40	45.14	5.11

Figure 2


C.E.F. HAY DRIER
Test No 3 - 1st Cut - July 1946
Slatted Floor Distribution System - Mow Size 30x40' - Depth of Hay 5½'
EXPERIMENTAL FARMS SERVICE OTTAWA
Humidity of outside air.
Moisture content of hay in field.
Moisture content of hay in mow.
Temperature of outside air.
Temperature in hay 1' depth.
Temperature
Humidity and Moisture Content
100
90
80
70
60
50
40
20
0
Hay Mixture - Red clover - 80%
167 ← Hay placed in mow - date and tonnage (green weight)
Fan operation, cold air, 13 cu ft per sq ft of mow; ¾" water pressure.
July 1 2 3 4 5 6 7 8 9 10 11 12

Central Experimental Farm, Ottawa, 1945 Test No. 2 and 2a

In 1945 the two hay curing systems as constructed in 1944 were used for a second set of tests with both hot air and cold air supply. For these tests the air flow was increased 50 per cent over the amount used in 1944 to 12 cu. feet per square foot per minute for each square foot of mow area at a pressure of one inch of water. (Table 1).

On July 11, ten tons of first cut alfalfa hay were placed in each of the mows at a moisture content of 50 per cent and this filled the mows to a depth of 6 to 7 feet. Drying in the cold air mow required 17 days with 250 hours of fan operation, while in the hot air mow the drying period was 9 days with 165 hours of fan operation (Figure 1). Air supplied to the hot mow ranged from 20 to 30 degrees warmer than the air supplied to the cold mow. In both mows the hay dried without heating or moulding at the bottom of the mow, but some of the hay spoiled at a depth of 1 to 2 feet. Most of the heating took place at a point below the hay fork track where the hay was more firmly packed by the dropping of the bunches from the hay fork.

The operation of the hay curing equipment in 1945 demonstrated that hay at 50 per cent moisture was too damp for curing by the equipment used, and suggested that drying to a moisture content of 30 to 35 per cent in the

field would provide for more satisfactory barn drying. Serious problems in distributing both the hay and the air also existed. It appeared that the volume of air was still too low and that 15 to 20 cu. ft. would be necessary instead of 12 cu. ft. per min. It was also apparent that weather conditions of low temperature or high humidity reduced the rate of drying of the hay in the cold air mow.

The quality of the dried hay was not significantly better than field-cured hay. Chemical analyses by the Chemistry Division, Science Service, revealed a carotene content of 12.50 mg./100 gm. in the fresh material and this dropped to 2 and 3 mg. in the cured hay regardless of the method of curing. The ash content was 7.70 per cent in the fresh material and remained approximately the same in the cured hay. Protein dropped from 15.07 per cent in the fresh material to 13.30 per cent in the field-cured material, 13.53 per cent in the hay barn cured with warm air and 14.68 per cent with cold air. No significant difference was shown in ether extract, crude fibre or nitrogen free extract.

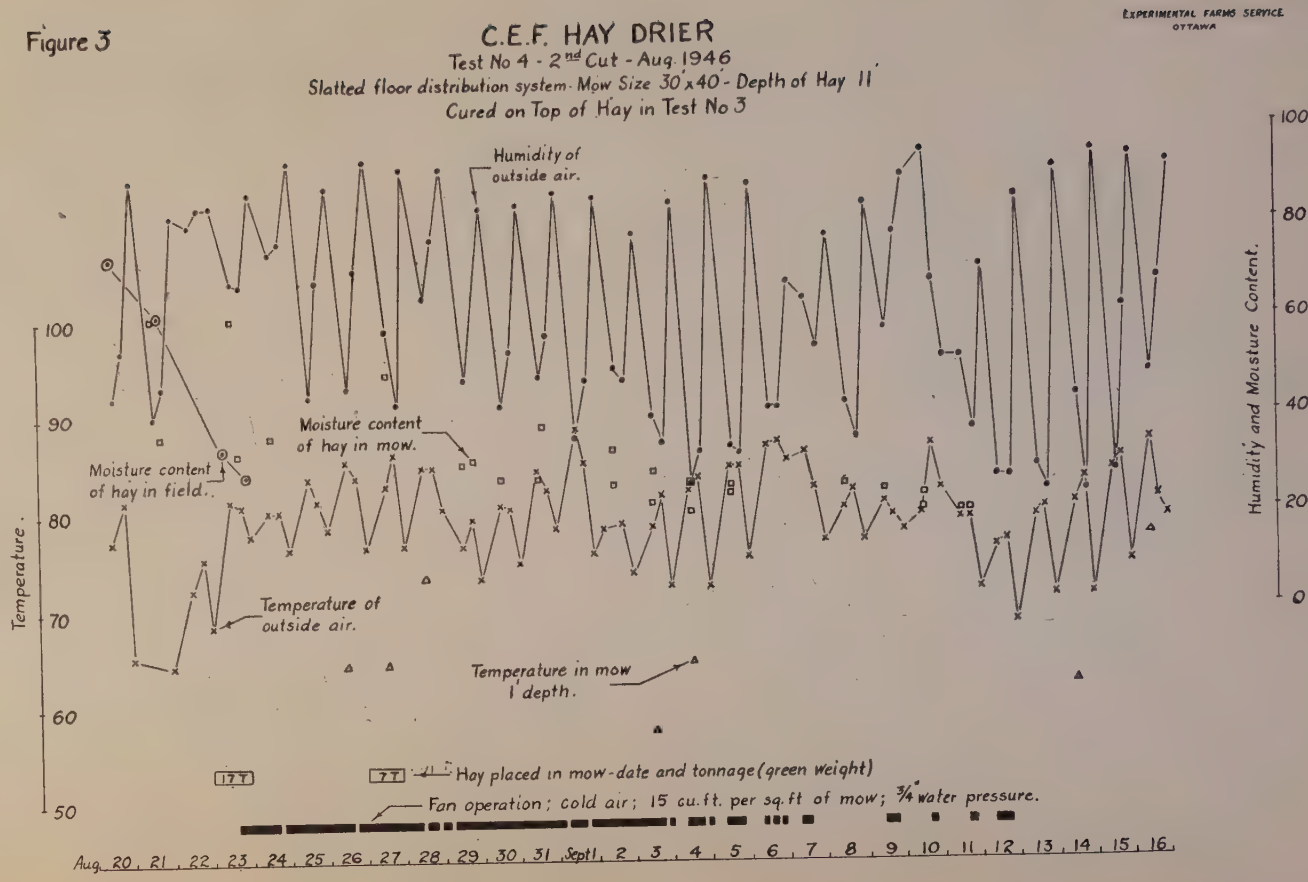
Central Experimental Farm, 1946, Test No. 3 and 4

In 1946 the hay curing experiment was conducted with cold air. The use of hot air was discontinued because of the supervision which was necessary with the heating unit, and also because of the cost of fuel and equipment. For test number 3 and 4, a single mow 30′ × 40′ was used, with a distribution system consisting of a single duct having slatted floors as laterals on each side. For details of installation, see Table 1.

In test number 3, first cut alfalfa hay at 40 to 30 per cent moisture content was placed in the mow to a depth of 5 to 6 feet and air was supplied at 13 cu. feet per minute. The drying period extended over 8 days (see Figure 2), with 112 hours of fan operation and the quality of hay was reasonably good. In test number 4, 17 tons of second cut clover hay were placed on top of the first cut hay and air was supplied at 15 cu. feet per min. per square foot of mow area. A total of 33 tons of hay based on its weight at storing filled the mow to a depth not exceeding 10 feet. The drying period for the second cut hay was 21 days (see Figure 3) with 321 hours of fan operation. This hay heated in spots and the quality of the hay was very uneven throughout the top of the mow.

Analyses showed considerable reduction in the chemical nutrients due to curing by all methods. Carotene to the extent of 23.14 mg./100 gm. in the fresh material dropped to 7.83 in the field-cured hay and to 6.48 in the barn finished material. Very little change occurred in the ash content during the curing process. Protein in the fresh material amounted to 14.80 per cent and was reduced to 9.83 per cent in the field-cured material and 11.24 in the barn-cured material. Ether extract amounted to 1.77 per cent in the fresh crop and 1.31 per cent and 1.28 per cent in the field and barn-cured hay, respectively. Crude fibre increased from 30.14 per cent in the fresh material to 35.59 in the field-cured and 34.15 per cent in the barn-cured. Beginning with 45.65 per cent of nitrogen free extract in the fresh material there was a very slight increase to 46.98 per cent in the field-cured and 46.93 per cent in the barn-cured hay. Preliminary determinations for digestible nutrients by the Division of Chemistry and

Figure 3


C.E.F. HAY DRIER
EXPERIMENTAL FARMS SERVICE
OTTAWA
Test No 4 - 2nd Cut - Aug. 1946
Slatted floor distribution system. Mow Size 30'x40'- Depth of Hay 11'
Cured on Top of Hay in Test No 3
Humidity of outside air.
Moisture content of hay in mow.
Moisture content of hay in field.
Temperature of outside air.
Temperature in mow 1' depth.
Temperature.
Humidity and Moisture Content.
100
90
80
70
60
50
100
80
60
40
20
0
17 T
7 T
Hay placed in mow-date and tonnage (green weight)
Fan operation; cold air; 15 cu. ft. per sq. ft of mow; 3/4" water pressure.
Aug. 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, Sept. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16

feeding trials by the Division of Animal Husbandry failed to reveal any significant difference in nutritive value of the hays produced by the various methods. It is planned to repeat these tests in 1947 and results will be reported at a later date.

Dominion Experimental Farm, Agassiz, B.C., 1946 Test No. 1

At the Dominion Experimental Farm at Agassiz, B.C., three hay curing tests were run in 1946. The equipment used consisted of centrifugal fan designed to deliver 16,000 cu. feet per minute at $\frac{3}{4}$ inches of pressure when driven by a G.E. 5 h.p. motor. The mow floor measured 30 × 36 feet and the duct unit was of the single main system with box type lateral, and the calculated air supply was 14.8 cu. ft. per min. per sq. foot of mow area. On each side of the main duct eight laterals were installed on 4 foot centres and these units were constructed with 1 × 8 and 1 × 12 inch lumber. (For other details, see Table 1). In each test the hay was spread over the mow with care to obtain as uniform distribution as possible.

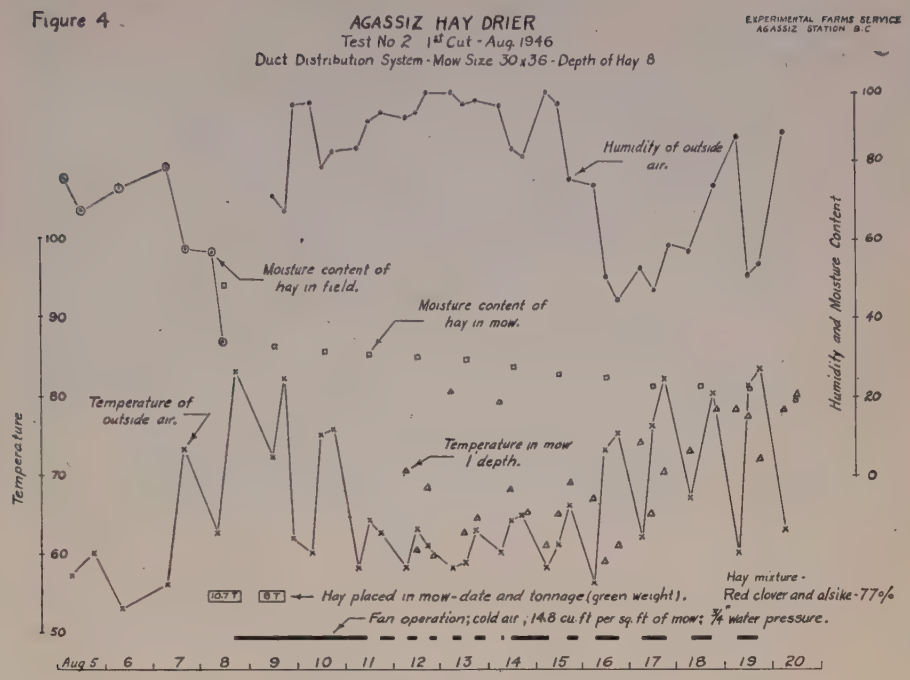
For test number 1, storing in the mow started on July 5, twenty-eight hours after the hay was cut. Eight loads were placed in the mow on July 5 at 42 per cent moisture content. Six loads were stored on the sixth at 42 to 36 per cent moisture, two loads were placed on July 7 at 51 per cent, making a total of 22.5 tons of hay which filled the mow to a depth of 10 feet. Between July 8 and July 18 the fan was operated continuously during periods of low humidity and intermittently during periods of high humidity, for a total of 156 hours. To operate the fan 648 kilowatt hours of power were used by the motor.

The quality of the hay as cured in test number 1 was not of high grade, even although the temperature in the hay did not exceed 100 deg. The top layer of hay, which was wet with rain before storage, moulded and carried a musty odour. The hay that was used for this test was more mature than is normally desired. This test was conducted under very adverse weather conditions and field-cured hay was badly weathered. Although the barn-cured hay was not of ideal quality, curing in the field of a large quantity would have no doubt resulted in complete spoilage of the fodder. Chemical analyses of some of the field-cured and barn-cured hay are compared in Table 2.

Agassiz, B.C., 1946 Test No. 2

The red and alsike clover hay which was used in test number 2 was cut on August 5 and storing in mow started on August 8. The eight loads placed in the mow on August 8 had a moisture content range of 47.6 to 39 per cent while the six loads hauled on August 9 ranged from 35.8 to 29.5 per cent. In all 18.73 tons were placed in the barn, filling the mow to a depth of about 8 feet. The hay used in test number 1 was previously removed. In curing this hay in the mow the fan was operated intermittently between August 8 and August 20 for 159 hours during which time the power consumption was 640 kilowatt hours. During the drying or curing period it rained on August 13 and 15. Temperature recordings taken at various depths in the hay showed that 80 degrees was the maximum hay temperature. (See Table 1 and Figure 4 for further details.) On the basis of general appearance, the hay seemed of good quality at the end of the curing period.

Figure 4.


AGASSIZ HAY DRIER
Test No 2 1st Cut - Aug. 1946
Duct Distribution System - Mow Size 30x36 - Depth of Hay 8
EXPERIMENTAL FARMS SERVICE
AGASSIZ STATION B.C.
Humidity of outside air.
Moisture content of hay in field.
Moisture content of hay in mow.
Temperature of outside air.
Temperature in mow 1' depth.
Temperature
Humidity and Moisture Content
10.7 T
8 T
Hay placed in mow - date and tonnage (green weight).
Hay mixture - Red clover and alsike - 77%
Fan operation; cold air; 14.8 cu. ft per sq. ft of mow; ¾" water pressure.
Aug 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

In this trial chemical analyses showed the barn-cured material to have a slight margin of superiority over swath-cured hay, while in comparison with cock curing there was no gain (see Table 2, Test No. 2). In the second trial most feeding constituents were present in higher amounts, thus indicating a better grade of hay than cured in the field.

Agassiz, B.C. Test No. 3

In this test hay was placed on top of the hay that was previously dried in test number 2. This hay was second cut red and alsike clover cut on August 27 when the clover was in full bloom. Due to favourable weather conditions the cut hay dried rapidly in the field with the samples showing 42.5 per cent moisture at 9.00 a.m. on the 28th, 34.5 per cent at 6.00 p.m. on the 28th, and 22.8 per cent at noon on August 29. The seven loads of hay hauled on the 28th ranged in moisture content from 42.5 to 34.5 per cent while the one load hauled on the 29th had a moisture content of 22.8 per cent. The total amount of hay as weighed from the field was 12.6 tons and this filled the mow (on top of the hay previously dried) to a depth of about $11\frac{1}{2}$ feet, or 6 feet of first cut and $5\frac{1}{2}$ feet of second cut hay.

During the curing period the fan was operated intermittently for 123 hours with one delay of 34 hours due to lack of power. On curing the second cut hay to about 18 per cent moisture, some 2.07 tons of water were evaporated. (See also Table 1 and Figure 5). After curing, the top layer of the hay carried definite traces of mould and was rather musty but the remainder of the hay was of reasonably good quality. Chemical data for this experiment as reported in Table 2 (Test 3) indicate a high quality product after the completion of drying. Unfortunately no field-cured hay

was made in this trial. Had sufficient material been available the comparative analysis would no doubt have been interesting since humidity conditions at that time of year would tend to retard field curing.

Hay Curing Operations, Ste. Martine, P.Q., 1946

As a hay curing unit had been installed at the Ste. Martine Agricultural School in 1946, a visit was made to the school to discuss details with the operators on the use of hay-curing equipment. To our knowledge this installation was the only other curing unit in operation in Eastern Canada.

The equipment used consisted of a 3 h.p. electric motor with centrifugal fan which delivered about 12,000 cubic feet of air at approximately $\frac{3}{4}$ of an inch of pressure. The distribution system consisted of a main central duct with slatted floor lateral sections. With a mow area of 30 × 36 feet the air supply was about 11 cubic feet per square foot of mow area.

Alfalfa-clover hay was cut in June from a field yielding about $1\frac{1}{4}$ tons per acre and the hay was placed in the mow at approximately 45 to 50 per cent moisture content. Storing proceeded as follows: first day, 4 loads; fourth day, 2 loads; sixth day, 6 loads, and seventh day 7 loads. With this hay the mow was filled to a depth of 13 to 14 feet. During the harvesting and curing operations the weather was continually dry and warm and the fan was operated 360 hours in 15 days consuming about 1650 kilowatts of power for about 25 tons of hay.

On about the tenth day, approximately 1 foot of hay was removed from the top of the mow because it showed signs of heating and moulding. However, the remainder of the hay cured in a very satisfactory manner and retained a good colour. In this curing operation the hay was placed in the mow over a period of several days and the weather conditions were very favourable for curing.

FACTORS IN HAY CURING OPERATIONS

Moisture Content of Hay

In the earlier experiments between 1939 and 1944, the hay was usually placed in the mow at a moisture content of about 50 per cent. Although hay could be taken from the field sooner at this moisture content the handling of the wet hay increased the labour and the curing operation was not satisfactory with cold air. In curing operations at Ottawa in 1944 and 1945 the quality of the hay stored at 45 to 50 per cent was poor due to excessive heating in spots. In the last two years most experiments have been conducted with hay at 30 to 40 per cent moisture. At or about 30 per cent moisture there is very little loss of leaf when handling hay and this tends to improve the quality, but by storing at this moisture content the hay must be left in the field for a longer time and thus may be subject to adverse weather conditions for drying. If hay can be dried satisfactorily in the field to 35 per cent moisture it often requires only a few additional hours to dry it to 25 per cent which is low enough for safe storage in any case and under these conditions a barn drier would seem to be unneccessary.

With hay at 50 per cent moisture content mow curing is difficult because of the large amount of water that must be evaporated and also because of the packing effect of the hay which necessitates high air pressures

in the duct system. The water that is evaporated to produce one ton of hay at 20 per cent is: 1200 pounds for hay at 50 per cent; 462 for hay at 35 per cent; 286 pounds for hay at 30 per cent and 133 pounds for hay at 25 per cent moisture content.

Even with the use of heated air, the mow curing of hay at 50 per cent moisture content was not entirely satisfactory in the 1944 and 1945 experiments at the Central Experimental Farm. Drying would have proceeded faster with the heated air but the air distribution was not even enough to produce satisfactory results.

Placing of Hay on a Barn Curing Unit

Moving of hay at 35 per cent moisture content to the mow takes considerably more work than moving hay at 20 per cent since the weight of material is about 25 per cent greater and as the greener hay is more difficult to handle. Spreading of moist long hay in the mow also involves additional work as careful spreading is absolutely necessary to obtain even air distribution and even curing. In the experiments at Ottawa in 1944 and 1945, when the main air duct installation ran across the mow, much of the heating took place through the centre of the mow under the hay fork track because of greater packing of the hay in this area. When the air distribution system was rebuilt for the 1946 experiments the main air duct was slatted on the sides and located directly below and parallel to the track, resulting in better curing at the centre of the mow.

The depth of hay that can be placed in the mow in one storage period varies according to the moisture content of the hay and also depends on the weather conditions during curing operations. In general, the results of experiments at Ottawa and Agassiz indicate that the depth of hay in a single filling should not exceed 8 feet and this depth has also been found reasonably satisfactory in some other experiments (6). The recommendations of the University of Wisconsin (7) are, however, a maximum of 6 feet and not over 4 feet in cool weather, and not over 2 feet per filling in cool damp weather. According to experiments conducted at Cornell University (8) no more forage should be placed in a drier than can be dried in 5 to 7 days.

The rate of filling a mow also affects the depth of hay that can be satisfactorily cured, and if hay can be placed into the mow over a period of 4 or more days, filling to a depth of about 7 or even 8 feet may produce satisfactory results. This method of storing was used with the Ste. Martine installation in 1946.

Air Distribution System Details

The inverted U-shaped box type lateral air distribution ducts were used at Ottawa in 1944 and 1945 and at the Agassiz Station in 1946, while the slatted floor type of lateral distributor was used at Ottawa in 1946. Inverted box laterals as developed in Virginia are used on many driers but there now appears to be a tendency to the slatted floor system in order to keep air pressures as low as possible when the volume of air supplied is increased.

As yet a method has not been devised which will evenly distribute the air through the hay in the mow. A distribution system could be developed that evenly distributes air against an even resistance across the mow but

there appears to be no practical means of evenly distributing the hay. The trend has been to increase the volume and pressure of the air at the cost of extra power in an attempt to obtain sufficient air flow through the high resistance packed spots in the mow for curing while more than the required volume of air is lost through loosely packed parts of the mow. To make this problem of air distribution more difficult to solve, more than one set of air resistance conditions develop as successive layers of hay are placed in the mow.

In the experiments which were conducted in 1944 and 1945 it was found that the air distribution was reasonably even when there were only 4 feet of hay in the mow, while with a depth of 8 to 10 feet little air passed through the hay and much air was lost along the walls of the mow. From this it was concluded that a slatted floor distribution system was needed over practically the entire mow for 3 to 4 feet of hay while a narrow distribution chamber was needed near the centre of the mow for 10 or 12 feet of hay. The distribution system installed in 1946 therefore consisted of a central duct 68 inches wide with slatted top and sides, and a slatted floor on either side with damper boards so that the slatted floors could be shut off when the hay depth exceeded 4 to 6 feet. Air-pressure readings and some improvement in the hay curing indicated that this method of flexible air distribution was an improvement, even though it did not overcome all of the spot heating of the mow where the hay was unevenly distributed.

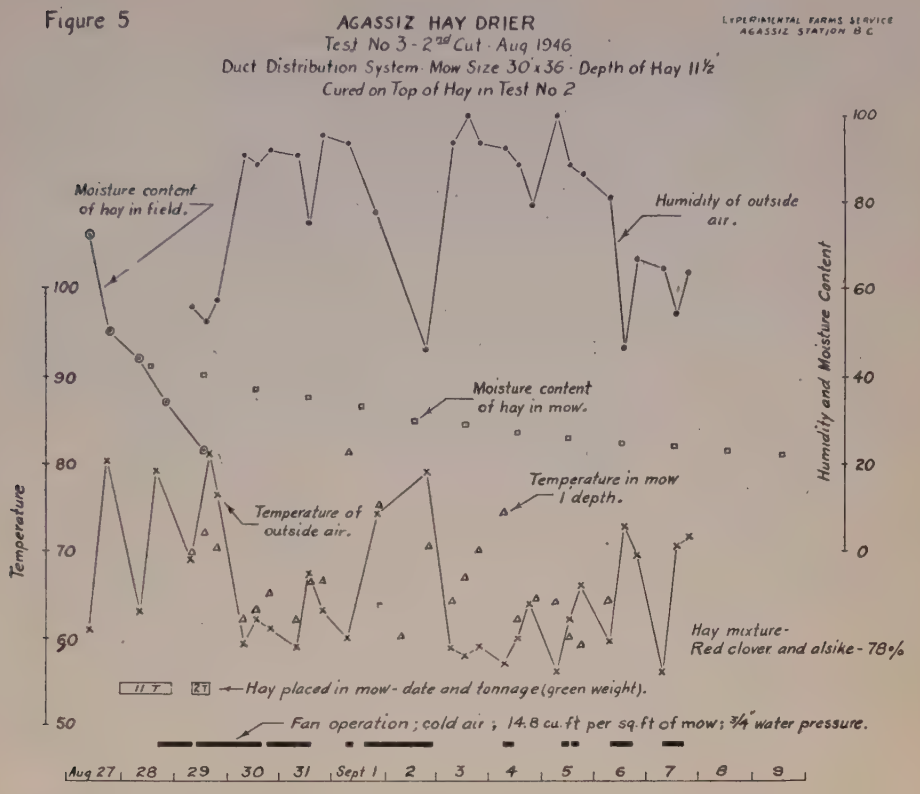
Air Pressure and Air Volume

When hay is placed over a hay curing system to a depth of 4 to 5 feet and when the hay is reasonably well spread with a minimum of tramping, curing can usually be successfully accomplished with a moderate flow of air at a rather low pressure. However, as the depth of the hay increases the fan capacity, air pressure and motor power must be increased. Pressure measurements taken at the Central Experimental Farm indicated that with 8 cu. feet of air per minute, $\frac{1}{2}$ inch of water pressure was required for 4 to 5 feet of hay; that with 15 cu. feet of air $\frac{3}{4}$ to $1\frac{1}{2}$ inches of pressure would be desirable with 15 cu. feet for 10 feet of long hay. Other workers have indicated that these pressures may have to be doubled for chopped hay. According to B. A. Jennings of Cornell University, 27 cu. feet of air may cure hay in 30 per cent less time than 15 cu. feet of air per minute. The installation cost for both fans and motors is, however, materially increased when this volume of air is used, and many rural power-lines would not carry a motor large enough for the fans. A fan with a 3 h.p. motor will deliver about 12,000 cu. feet per min. at about $\frac{3}{4}$ inch of pressure, or 15 cu. feet per sq. foot, for a mow of 800 square feet; while a $7\frac{1}{2}$ h.p. motor and fan will deliver about 25 to 30,000 cu. feet or 15 cu. feet for a mow having an area of 2000 square feet.

Fan Operation

With the cold system the fans were not operated during damp or rainy weather in the 1944 experiments at Ottawa and it was found that the hay temperature sometimes went up to 135 degrees. From this it was concluded that continuous fan operation was desirable in fair weather and that

Figure 5


AGASSIZ HAY DRIER
Test No 3 - 2nd Cut - Aug 1946
Duct Distribution System - Mow Size 30'x36' - Depth of Hay 11½'
Cured on Top of Hay in Test No 2
EXPERIMENTAL FARMS SERVICE
AGASSIZ STATION B.C.
Moisture content of hay in field.
Humidity of outside air.
Moisture content of hay in mow.
Temperature in mow 1' depth.
Temperature of outside air.
Temperature
Humidity and Moisture Content
Hay mixture - Red clover and alsike - 78%
11 T
21
← Hay placed in mow - date and tonnage (green weight).
Fan operation; cold air; 14.8 cu. ft per sq. ft of mow; ¾" water pressure.
Aug 27 28 29 30 31 Sept 1 2 3 4 5 6 7 8 9

shut-down periods should not exceed possibly 4 hours in damp weather. Even although the weather is damp, evaporation takes place due to heat generated in respiration (References 3 and 14). Practically no moisture is absorbed unless the moisture content of the hay is below 12 to 15 per cent.

Heated Air in Mow Curing

It was found in the experiments conducted in Ottawa in 1945 that the use of heated air reduced the curing period from 17 to 9 days and that it was possible to obtain a reasonably rapid rate of drying of the hay even when the outside air had a relatively high humidity. By drying the hay more rapidly it is possible to place more hay in the mow at an earlier date, and by drying the hay more rapidly than with cold under adverse weather conditions when field curing was not possible, the use of heated air method proved to be superior to the cold air method of barn curing hay. However, due to the fact that the present barn curing system cannot force air evenly through the hay, heating or moulding occurred in spots even when heated air was used for curing. In areas where it is difficult to cure hay it may often be economically possible to use $2.00 worth of fuel to dry each ton of hay. It is unlikely that heated air will be used in barn curing until this method of curing is improved. A fire hazard also exists when heated air is used which makes it necessary to keep a watchman with the equipment or to install elaborate equipment controls for fire protection.

Cost of Barn Curing Equipment

Curing equipment costs vary according to the size of mow involved, the air pressure required, location of power supply lines, etc. On the basis of 15 cu. feet per square foot at 1 inch pressure, the cost of a motor, fan, lumber and labour for building the duct system is at present approximately $600 for a mow measuring about 32 ft. × 32 ft. or about 60 cents per square foot of mow. This does not include power-line connection costs.

The power consumption of a 5 horse power motor is about 5 kilowatts per hour and the power cost at 2 cents per kilowatt hour may range from 75 cents to $1.50 per ton of dry hay. The total cost of drying might be estimated as follows: Equipment depreciation at 10 per cent, $50; interest at 5 per cent on half the cost, $12.50; care of equipment at 50 cents per day for 30 days, $15; and power at $1.00 per ton at 30 tons per year or a total of $107.50 per season or approximately $3.30 per ton of dry hay.

SUMMARY

1. The barn hay drier was introduced in an attempt to obtain a better quality of hay by improving the method of curing hay and to eliminate some of the weather hazards in field curing the hay crop. The barn method of curing hay which was developed in the South Eastern Region of the United States may be of value in that area but due to variations in climatic conditions, methods of handling hay, barn design, etc., it is not necessarily adaptable to conditions which exist in this country. Mow driers are not dehydration plants in which large quantities of green or slightly wilted crops can be dried regardless of weather conditions and method of handling the crop. During the past 10 years many changes have been made in mow curing equipment and it can still be considered in a stage of development. The results of experiments conducted to date at Ottawa and Agassiz illustrate some of the limitations in the mow curing of hay with the equipment that has been developed to date.

2. In all of the curing experiments which were conducted at Ottawa and Agassiz there was a tendency for some of the hay to spoil or mould at the top and in spots of the mow, while the remainder of the hay usually cured satisfactorily when the conditions of operation were reasonably favourable.

3. As yet a means of evenly distributing air through a mow of hay has not been developed. This results in poor air use efficiency and usually causes hot spots and moulding in parts of the mow. The accumulation of moisture and slow drying at the top of the mow is another deficiency in the mow drying method of curing hay. A new principle of drying may have to be evolved before mow curing will be accepted as an adequate means of curing hay.

4. The use of heated air in curing hay decreases the period of time required for drying but it also involves an additional cost for fuel and introduces a fire hazard. In regions where the climatic conditions for curing hay are consistently unfavourable for field curing, heated air may be necessary. At present the barn curing system does not use heat efficiently due to air losses.

5. The results of the experiments which have been conducted have illustrated some of the limitation in the barn curing of hay and the tests have shown that the following operation and equipment features or methods are desirable or constitute the minimum requirements in the barn curing of hay. It cannot be concluded, however, that hay can be successfully cured without moulding under all conditions by providing for these specifications; nor can it be concluded that the barn curing method is adaptable to all regions, or practical on any particular farm.

(a) At least 15 cubic feet of air per minute per square foot of mow area at one inch static water pressure is required for long hay that is stored to a final depth of 10 feet. A pressure of $1\frac{1}{2}$ to 2 inches appears to be necessary for chopped hay.

(b) A distribution system consists of a central duct at least 3 feet high with side walls having full length damper doors, and a slatted floor lateral system with dampers at the central duct, designed in such a manner that the air distribution can be controlled through the slatted floor for shallow depths of hay and through the sides of the main duct for greater depth of hay.

(c) For cold air systems the moisture content of the hay when placed in the mow should not exceed 37 per cent. Hay must be distributed evenly in the mow to aid in even air distribution with a minimum of tramping on long hay and no tramping on cut hay.

(d) Fan operation with cold air systems should be almost continuous from the time the first load is placed in the mow with shut-off periods not exceeding 4 hours even during rain.

(e) In loading the mow the maximum depth of long hay should not exceed 7 to 8 feet for any one filling and it would be preferable to make the filling over a period of at least 3 days. The total depth for long hay should not exceed 11 to 13 feet. If adverse weather conditions are anticipated the depth on a single filling should be less than 7 feet.

(f) The central duct should be placed directly below and parallel to the hay fork track. Air speeds in this duct should not exceed 1500 feet per minute and slatted floors should extend to within 6 feet of the mow walls.

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THE INFLUENCE OF ANTIBIOSIS IN THE PATHOGENICITY OF *HELMINTHOSPORIUM SATIVUM*[1]

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[Received for publication August 12, 1947]

In studying the occurrence of *Helminthosporium sativum* P. K. & B. on wheat stubble, rather strong evidence of antibiosis was encountered. The results of these studies will be reported later. At the same time, investigations on the resistance of wheat seedlings to *H. sativum* were under way, and in this work wide variations in degrees of infection were observed from time to time. These fluctuations were difficult to explain until the above-mentioned work on stubble indicated antibiosis as a likely factor. This approach was explored preliminarily with promising results, and further experimentation was outlined.

LITERATURE REVIEW

An extensive literature on antibiosis has developed relating to cereal root diseases. In Canada, pioneer work was done by Sanford and Broadfoot (12) and Henry (6, 7 and 8). Later, Sanford (13) reviewed pertinent literature in this field. It was shown that practical biological control of certain diseases, through antibiosis, was beset with many difficulties. The indirect approach, however, in which the soil microflora is modified by cropping or other treatments, to promote an increase in the desired antagonistic organisms, has been successful. Weindling (17) also mentioned the difficulties of applying biological control methods except by the indirect approach. In a comprehensive review of microbial antagonism, Waksman (16) points out, especially in regard to the control of many soil-borne diseases, that investigators have had reasonable success with the indirect method. His review, however, indicated that the direct approach, in which specific antagonistic organisms are added to the seed or soil, was not generally practicable. The direct approach has given excellent results many times under experimental conditions as mentioned in the above reviews and more recently by Goodman and Henry (5). Russian investigators studied the direct method rather extensively. A few references relating to root diseases of cereals may be mentioned. Novogrudski (11) reported on methods for the isolation from soil and from diseased plants of bacteria lysogenic to fungi, including some pathogens. In this manner, strains of bacteria lysogenic to *Fusarium graminearum* and *F. lini* were obtained. Reasonably good protection of wheat and flax seedlings was secured, in pot inoculation tests, by the use of the respective lysogenic bacterial strains. The application of bacterial antagonists to seed for the control of certain diseases was investigated by Beresova and Naoumova (1). They used the term "bacterization" to describe their technique.. In flax, germination was improved by bacterization and infection of *F. lini* reduced. Seedling infections of wheat also were reduced, particularly by species of *Pseudomonas* and *Achromobacter*. The bacteria were best applied

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[2] Officer-in-charge.

to the seed grain in a peat base. Jensen (10) reviewed the Russian work on bacterization and came to the conclusion that the use of specific antagonists was a promising field for investigation.

Frequent reports in the literature reveal many fungi, some bacteria, and soil organisms in general to be antagonistic or antibiotic to *H. sativum*. In most efforts to employ antibiosis in biological control of diseases, organisms isolated from the soil were used. This was particularly true in the direct approach, when such organisms were applied to the soil, at seeding time, or added to the seed as in bacterization. In the present study, the importance of soil organisms was recognized but most attention was given to the natural surface flora, mainly bacterial, on wheat seed and other parts of the wheat plant.

EXPERIMENTAL

As mentioned in the introduction, good evidence of antibiosis was observed in studying the occurrence of *H. sativum* on wheat stubble in nature. It was thought that wheat stubble in general would be a good medium for this fungus and might serve as a common source of natural inoculum. Surveys indicated, however, that on the whole only small amounts of *H. sativum* could be found on stubble from most fields. There were nevertheless occasional fields that showed rather high percentages of this pathogen on the stubble. The appearance of *H. sativum* on washed and incubated stubble pieces, in our survey studies, was thought to have arisen from well-established infections that originated while the plant was still growing.

Some inoculation experiments with *H. sativum* were designed to explore the possible influence of the natural flora found on stubble and straw pieces. These were followed by similar tests with wheat seeds and seedlings and studies of bacterial isolates from plant surfaces.

Experiments with Cereal Stubble and Straws

Several inoculation trials were conducted using wheat stubble pieces as a medium. One typical test will be described. Some stubble material was collected and washed under the tap. One-half was boiled five minutes to destroy any natural flora. Both lots were set up in Petri dish moist chambers and inoculated with a conidial suspension of *H. sativum*. A good sporulating growth of the fungus was obtained on the sterilized stubble pieces but no growth or very sparse growth of *H. sativum* on the unsterilized pieces, where, however, a good growth of miscellaneous fungi and bacteria developed. It was suspected that the natural stubble was contaminated by antibiotic organisms originating from the soil. Some confirmation of this was obtained when it was found that sprinkling sterilized, inoculated straws with unsterilized soil inhibited the growth of *H. sativum*. It would appear, therefore, that the natural stubble is not readily colonized by *H. sativum*. This explains the generally low percentages of this fungus obtained in our stubble surveys (14). It is realized that the sterilization of the stubble fragments may have altered the medium (stubble) other than by the elimination of the surface flora. This question will received further attention in studies now under way.

FIGURE 1. (A) On the left a colony of *Helminthosporium sativum* growing on a potato dextrose agar plate. Three Thatcher wheat kernels, which had been incubated at 24° C. for 24 hours, were placed at the margin of the colony about 3 days prior to the time of photographing. A bacterial colony has developed around these kernels and inhibited the growth of the fungus. The plate on the right contains three kernels which were placed at the margin without incubation, otherwise comparable to the plate on the left. In the case of the dry kernels, very little or no bacterial growth appeared and the fungus was not inhibited. (B) Similar in general to (A) but showing three incubated kernels of barley on the left and oats on the right. (C) A smear made by placing a kernel of Thatcher wheat, incubated 48 hours, in a small drop of sterile water on a slide for a short time and showing an abundance of the type of bacterium usually observed in these studies. × 1200. (D) A smear made as in (C) from the coleoptile of a barley kernel growing in a plate similar to that shown in (B). The usual bacterium is seen in great numbers, presumably originating from the seed surface. × 1200.

In another type of experiment, pieces of the green culm were taken from a growing wheat plant and employed in inoculation tests. The pieces were taken well above the soil surface to reduce chances of contamination from the soil. One-half of the sample was incubated in Petri dish moist chambers for two days at 24° C.; the remaining half was kept dry in a similar dish for two days, then moisture was added; and both lots were inoculated with a conidial suspension of *H. sativum*. Very little growth of the fungus was obtained on the incubated pieces where presumably the surface flora had flourished under the prior period of incubation. In the case of the dry pieces, the *H. sativum* conidia were able to germinate and commence growth at the same time as the natural flora and apparently compete with it. Under such conditions *H. sativum* was not greatly inhibited and a good sporulating growth resulted. Several tests of this type were conducted with similar results. It appears that an antibiotic flora exists, quite commonly, on the surface of the culm and becomes active after a short period of incubation.

In addition to the above experimentation, the surface flora was studied by means of direct microscopic examinations, smears, and isolations. Pieces of wheat culms, green and ripe, and mature kernels were incubated for a short time; then strips of the epidermis was taken for examination. An abundance of bacteria were seen in almost every case. Commonly there was a rather uniform colonization over the epidermis but occasionally the bacteria were grouped at various points. Smears were easily made by placing a seed or a fragment of culm in a drop of sterile water and allowing incubation for at least 24 hours, when the drop would contain an abundance of bacteria. Such a preparation was dried, fixed and stained in the usual procedure for bacterial smears. Isolations were easily made from incubated material. The bacterium generally obtained was a medium to small motile rod. The isolates and some tests conducted with them will be discussed below.

Experiments with Wheat Seeds and Seedlings

The importance of an antibiotic influence, if any, in inoculation tests of seeds and seedlings to study resistance to *H. sativum*, was recognized and experiments were designed to explore the problem.

A test was conducted to compare dry wheat seed with seed incubated for various periods of 24° C. The kernels were kept separate, when set up for incubation in a Petri dish moist chamber, to avoid contamination from kernel to kernel. If antibiosis depends upon the development of a surface flora, one would expect greater antibiotic influence with increasing growth periods. At the proper time, seeds were selected and placed at the margin of a young *H. sativum* colony growing on potato dextrose agar. Whether or not the seed carried antibiotic bacteria was indicated by the inhibition of the fungus growth adjacent to it as the bacterial colony originating from the seed developed. Strong inhibition caused a marked indentation of the colony. No or little inhibition, of course, allowed the fungus to advance around and over the seed (Figure 1, A and B). The results are shown in Table 1.

TABLE 1.—THE INFLUENCE OF LENGTH OF TIME OF SEED INCUBATION ON THE DEVELOPMENT OF ANTIBIOTIC BACTERIAL GROWTHS

Treatments	Inhibition of *H. sativum*			Total number of seeds
	Strong	Slight	None	
Dry seed	3	4	13	20
Incubation for 2 hours	5	2	13	20
Incubation for 8 hours	2	6	12	20
Incubation for 16 hours	9	8	3	20
Incubation for 24 hours	16	3	1	20

It will be seen that there was very little antibiosis until a period of 16 hours of incubation was reached, which would indicate a coincidence with bacterial growth. The maximum or approximate maximum was reached in 24 hours. At this time the seed had started to germinate.

Another inoculation experiment was designed to determine if infection of wheat seedlings by *H. sativum* was influenced by the surface flora of the seed. The experiment was set up in tubes by the method previously described by Simmonds and Sallans (15). In this technique, a six-inch strip of blotter paper is folded to form a small shelf about 2 inches from the top of a test-tube into which it is fitted. Water is added to the level of the shelf. The seed, one for each tube, is placed on the shelf. No further attention is required for at least a week. Seeds of the Reward variety were used in the present test. One-half of the seed lot was incubated for 24 hours after being placed in the tubes; at the end of this time, the other half was placed in the tubes and inoculated immediately with a conidial suspension of *H. sativum*. The incubated seed were also inoculated at this time. The inoculum suspension was made from good sporulating potato dextrose slant cultures, about 10 days old. It was divided into two portions, one for each series to avoid contamination between incubated and dry seed. A drop of inoculum was placed on the seeds with a glass rod. The seeds were allowed to grow for 7 days, when readings were made for the characteristic *H. sativum* lesions on the coleoptiles. The results are given in Table 2.

TABLE 2.—THE NUMBER OF SEEDLINGS SHOWING LESIONS AFTER INOCULATION OF DRY AND INCUBATED WHEAT SEED WITH *Helminthosporium sativum*

Treatment	Lesions		Clean	Doubtful	Total
	Severe	Slight			
Dry seed	37	9	16	10	72
Incubated seed	12	10	43	7	72

In the incubated seed where the antibiotic surface flora presumably was active, 43 of the seedlings were clean or free of lesions and a total of 22 showed lesions. In the dry seed series without the influence of an active

surface flora, only 16 were clean and a total of 46 had lesions. Several similar trials were conducted using seeds of other wheat varieties and with similar results. In some cases, incubation provided almost perfect protection from infection.

An inoculation experiment was devised in which the surface flora was eliminated, in part at least, by formalin treatment, to provide a suitable comparison with incubated or dry seed. A sample of wheat seed was incubated 24 hours, then one-half was treated with formalin solution by the dip method, as used for smut control, and one-half left untreated. A total of 24 seeds of each lot was then set up in test tubes, with an additional series of dry seed from the same source. All were inoculated at the same time, with care being taken to avoid contamination between series. At the end of 7 days, the seedlings which grew from the seeds were observed for coleoptile lesions caused by *H. sativum*. The results are shown in Table 3.

TABLE 3.—THE NUMBER OF SEEDLINGS FROM DRY SEED, INCUBATED SEED, AND INCUBATED SEED TREATED WITH FORMALIN, SHOWING LESIONS AFTER INOCULATION WITH *Helminthosporium sativum*

Treatment	Lesions		Clean	Doubtful	Total
	Severe	Slight			
Dry seed	10	2	12	—	24
Incubated seed	2	1	20	1	24
Incubated seed treated with formalin	21	0	2	1	24

The results show a striking difference between incubated seed treated with formalin, to eliminate antibiotic natural flora, and untreated incubated seed. Almost all seedlings from the formalin treated seed bore lesions on the coleoptile, whereas the untreated seed with an active natural flora showed very few seedlings with lesions. The dry seed gave intermediate results which may be explained by the slow start and development of the surface flora in comparison with the flora on the previously incubated seed. The results of this test have been confirmed several times by similar trials.

Miscellaneous Experiments

Many exploratory tests were conducted with bacterial isolates known to be antibiotic to *H. sativum*. Most of these isolates were obtained from wheat seeds. Cultural studies were also made to determine antibiosis of suspensions of surface flora from seeds and other parts of the wheat plant.

An experiment using one of the antibiotic bacterial isolates from Reward wheat kernels will be described. A small sample of Reward seed was dipped in the bacterial suspension, then placed in test tubes, as explained above for seedling infection observations; a similar quantity was dipped in water and so placed. Both were incubated at 24°-25° C. overnight, then inoculated by placing on each kernel a drop of a conidial suspensions of *H. sativum*. After 7 days, the seedlings were examined for coleoptile lesions, with results as shown in Table 4.

TABLE 4.—THE NUMBER OF SEEDLINGS FROM SEED TREATED WITH A BACTERIAL SUSPENSION AND FROM SEED DIPPED IN WATER, SHOWING LESIONS AFTER INOCULATION WITH *Helminthosporium sativum*

Treatment	Seedlings showing			Total
	Lesions	Clean	Doubtful	
Dipped in bacterial suspension	5	50	17	72
Dipped in water	23	39	10	72

It will be seen that the bacteria gave considerable protection to the seedlings. Tests of this nature would be more satisfactory if the seeds to be treated with various bacteria could be safely and thoroughly surface sterilized previous to testing. Formalin as employed in one of the tests mentioned above has been fairly satisfactory but has not been tried extensively. Several tests, such as the above, were conducted with seeds and pieces of straws with almost invariably good protection indicated.

Many small trials were conducted to demonstrate the antibiosis of surface bacteria to *H. sativum*. One of the most useful tests for this purpose was to start with a colony of *H. sativum* in the centre of a potato dextrose agar plate, and then place incubated seed or other specimens at points on the margin of the colony. The seeds or specimens received no previous treatment other than the incubation. Inhibition of growth was noticeable in a day or so, if antibiosis occurred. With this method, seeds of several varieties of wheat grown at Saskatoon were tried. All lots showed a good percentage of seeds with strong to slight antibiotic bacterial growths. There were indications of varietal differences in the degree of antibiosis shown, but of course only small numbers of seeds were involved. Thatcher wheat grown in 1946 at Saskatoon, Lethbridge, Harrow, Paddockwood, Beaverlodge, and Winnipeg was tried. Here again antibiotic bacteria were common in all samples, with some differences between regions indicated.

In a similar manner, surface flora from various parts of the wheat plant were tested for presence of antibiotic bacteria. Pieces of culm or leaves, from specimens collected in the summer, were incubated for 24 hours, then washed to obtain a suspension of the surface organisms. Drops of these suspensions were tested, and antibiotic bacterial growths developed commonly.

The germination of *H. sativum* conidia in agar was definitely retarded in the vicinity of antibiotic bacterial colonies growing from incubated wheat seed.

DISCUSSION AND CONCLUSIONS

It appears from the results of the above investigations that certain bacteria antibiotic to *H. sativum* are commonly found on the surface of wheat seeds and other parts of the wheat plant. A complete description or identification of the bacterium or bacteria concerned was not undertaken

in this work. By direct observation, the most abundant bacterium in most cases was a short motile rod. When isolations were made, a bacterium of the same gross morphology was most frequently obtained. Stained smears confirmed these observations (Figure 1, C and D). A culture of the most common type observed was turned over to Prof. V. E. Graham of the Dairy Department, University of Saskatchewan, who kindly consented to make preliminary studies of it. His investigations indicated that the bacterium might be an unusual one and therefore merited extensive and careful studies, which he has now under way. The writer suspects that there may be several species of surface-inhabiting bacteria. A recent paper by James, Wilson and Stark (9) is of interest in connection with bacteria associated with wheat samples. These authors found in their many isolations from wheat samples two persistent species of bacteria, one of which was identified as *Bacterium herbicola aureum*, the other belonging to the genus *Pseudomonas*. Both were considered to be epiphytic on wheat. Reference was made in the paper to earlier work by Burri (2) and Duggeli (3) on the bacterial flora on plant surfaces. The writer did not see these papers but read a later one by Duggeli (4). In the latter paper, Duggeli described *B. herbicola aureum* and mentioned *B. fluorescens*, both of which were found on wheat seeds and seedlings. All of these investigators believe that a definite bacterial flora occurs on plants and that chance contaminations from the soil play a small part. The writer holds this view. That the surface bacteria may be antibiotic was not mentioned by the above workers.

The results of the above experiments demonstrate, it is believed, the existence of a bacterial surface flora on seeds and other parts of the cereal plants, antibiotic to *H. sativum*, a common root disease pathogen. These bacteria appear to be prevalent and widespread. They may, therefore, by their tendency to inhibit growth, play a prominent role in inhibiting the infection of cereals by this fungus. The surface bacterial flora is considered quite separate and distinct from chance antibiotic contaminations from the soil. This point remains to be proved. The abundance of the bacteria on the surface of the coleoptile, originating from a seed carrying surface bacteria, indicates it is believed a definite surface spreading characteristic of the bacterium concerned (Figure 1, D). Antibiotics from the soil may be involved in many cases, but it is doubtful if they are prominent as plant surface inhabitants, except possibly on stubble and such debris which may be readily contaminated by soil.

Preliminary tests have shown that the surface flora on wheat seed after incubation must be considered in making varietal seedling trials to determine resistance. This phase of the study is being continued. It is not beyond probability that antibiotic bacterial flora may play a very important role in respect to disease resistance in general. It may be the host's first line of defense, and more studies along this approach are needed. It would appear that although much attention has been given to antibiotics from the soil and their application in disease control, very little attention has been directed to the natural surface flora. The presence of antibiotics on seed must also be considered in the treatment of seed with various fungicides.

SUMMARY

Experiments were conducted with wheat stubble, culm pieces, and kernels inoculated with *H. sativum*, the results of which indicated a bacterial surface flora antibiotic to this pathogen.

Evidence is submitted to support the idea of a natural bacterial plant surface flora which is prevalent and commonly antibiotic to *H. sativum*. Such a flora is believed to be separate and distinct from chance contaminations from the soil.

The significance of this flora in seedling testing for varietal resistance in wheat to *H. sativum* and in seed treatment studies was mentioned. The possible importance of an antibiotic surface flora in resistance studies in general was also pointed out.

ACKNOWLEDGMENTS

The author is very grateful to Dr. V. E. Graham, for his preliminary studies of the bacterial isolates obtained in these investigations. He wishes also to thank members of the staff, especially Dr. B. J. Sallans, for many helpful consultations while the work was in progress. Thanks are also due to Mr. M. Anderson, Technician, for his careful preparation of many experiments.

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